CURRENTS IN FRENCHMAN BAY

AREA OF LAKE ONTARIO

1968

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Great Lakes Surveys Program
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CURRENTS IN THE FRENCHMAN BAY AREA OF LAKE ONTARIO 1968

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ABSTRACT

Two recording current meters were operated from June to August, 1968 in 12.7m (42 feet) of water at distances of 2.42m (8 feet) and 4.6m (15 feet) from the bottom approximately 1.6km (1 mile) offshore in the Frenchman Bay area of Lake Ontario. A time series analysis was carried out on the resulting data for the various months. A maximum current of 21 cm/sec. (0.69 fps) observed was significantly lower than results obtained by similar current meter studies in adjacent areas and farther offshore. This appears to be a result of the shore geometry which reduced the currents in the area. Both the directions and persistence factors agree with results of other studies. Wind does not appear to be directly responsible for currents in the area which are produced as a result of diurnal, inertial and Lake Ontario free oscillation effects. The thermal regimes were a direct consequence of inertial effects.

CURRENTS IN THE FRENCHMAN BAY AREA OF LAKE ONTARIO 1968

INTRODUCTION

The Hydro-Electric Power Commission of Ontario is presently constructing a large thermal nuclear generating station on Lake Ontario in the area of Frenchman Bay. This generating station will utilize lake water for cooling purposes with an offshore submerged intake and an onshore surface discharge. The area is heavily used for recreational purposes by boaters, particularly in the enclosed Frenchman Bay basin where there is little water movement through the small harbour entrance. It was therefore considered necessary to determine whether the thermal discharge will change any of the existing water movement pattern or thermal regimes in the area.

The Ontario Water Resources Commission initiated an environmental study program consisting of detailed water chemistry monitoring, dye dispersion studies (Palmer, 1968), and current measurements to determine the existing conditions in the area before the start of operation of the plant.

This report discussed the water movement and thermal characteristics of the area as determined through the operation of two recording current meters at various depths for the period May to September, 1968. The data collected from these meters enabled a determination of the physical driving

mechanisms responsible for the currents and the thermal characteristics of the area by employing standard time series analytical techniques. Previous studies conducted in the Toronto area (Hamblin, 1967) and further offshore at Pickering are not directly applicable to the region adjacent to the power plant where shore geometry will be the major influence in the water movement and thermal characteristics. These studies, however, provide a basis for comparison of local patterns observed with larger scale patterns for the northern shore at the western end of Lake Ontario.

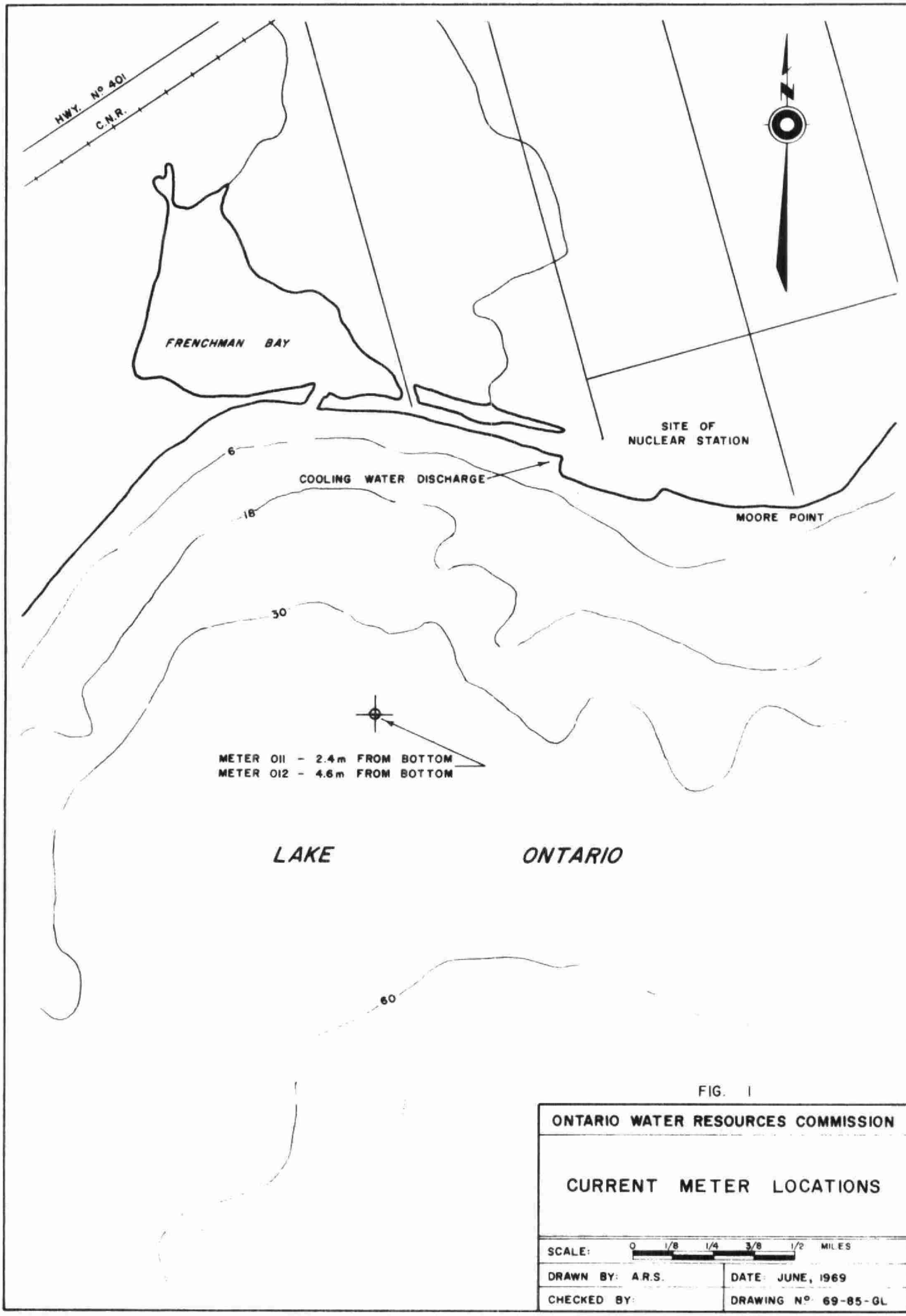
PURPOSE

The purpose of this study was to determine existing water movement and temperature regimes in the area offshore of the thermal nuclear generating station at Pickering, and to determine the fundamental physical mechanisms responsible for these patterns.

OUTLINE OF THE STUDY PROGRAM

General

Two recording type current meters (Plessey Type MO2) were installed in 12.7 meters (42 feet) of water at distances of 2.42 meters (8 feet) and 4.6 meters (15 feet) from the bottom (see Figure 2) on a submerged buoy support system approximately 1.6 km (1 mile) offshore (see Figure I). The depths of the meters were dictated by the support system, which for practical purposes is limited to water depths in excess of 12.2


HWY. Nº 401
C.N.R.
FRENCHMAN BAY
SITE OF
NUCLEAR STATION
COOLING WATER DISCHARGE
MOORE POINT
6
18
30
60
METER 011 - 2.4 m FROM BOTTOM
METER 012 - 4.6 m FROM BOTTOM
LAKE ONTARIO
FIG. 1
ONTARIO WATER RESOURCES COMMISSION
CURRENT METER LOCATIONS
SCALE: 0 1/8 1/4 3/8 1/2 MILES
DRAWN BY: A.R.S.
DATE: JUNE, 1969
CHECKED BY:
DRAWING Nº 69-85-GL

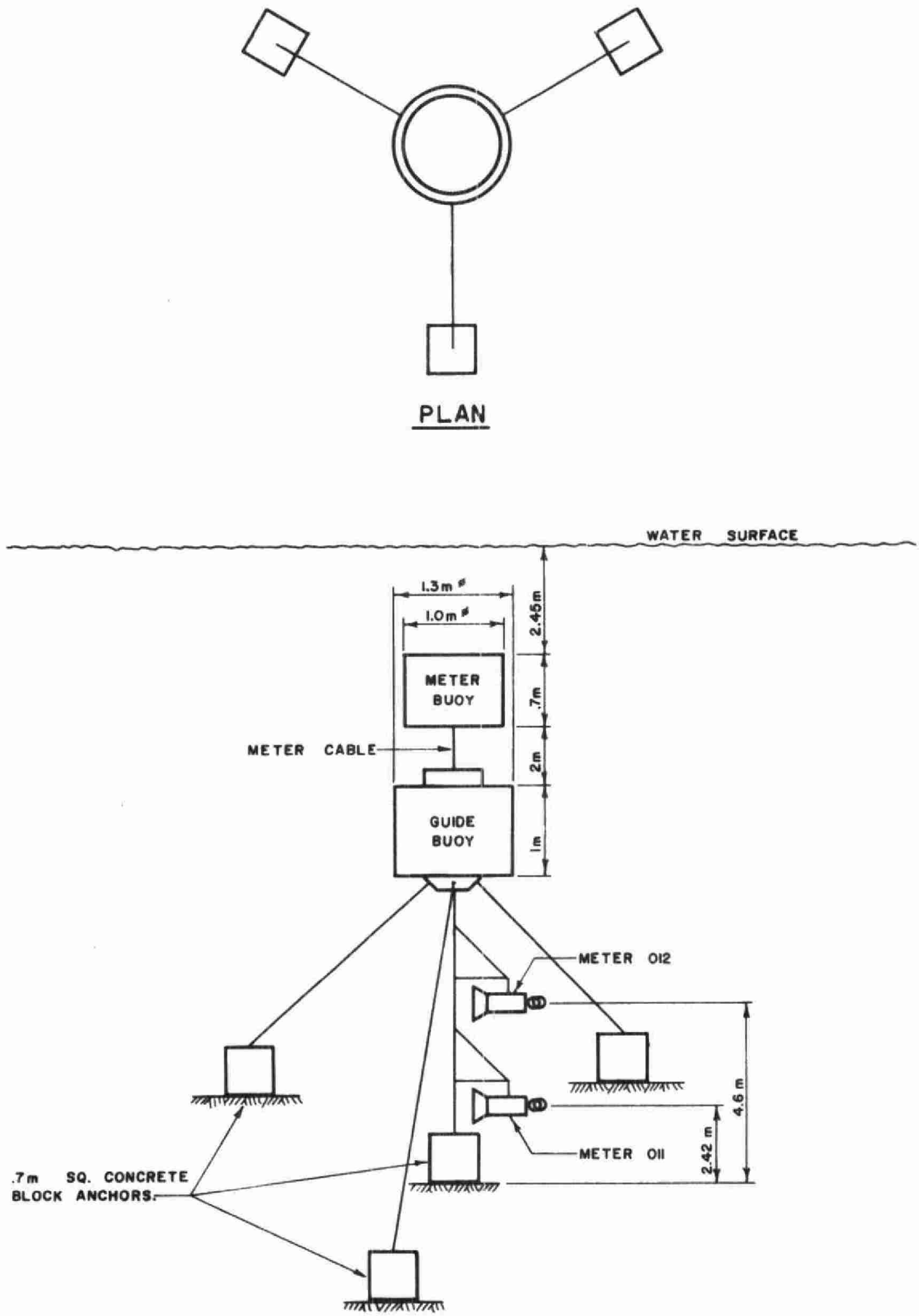


FIG. 2

ONTARIO WATER RESOURCES COMMISSION	
SUPPORT SYSTEM	
SCALE: NOT TO SCALE	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 69-84-GL

DESIGNED BY STELTNER DEVELOPMENT
AND MANUFACTURING CO. LTD.

meters (40 feet), and the limitation of the wave heights in the area. As there were no wave height records in the area of the proposed installation, the ten-year design wave height of 1.82 meters (6 feet) at Port Credit (Baines, 1962) determined by standard wind casting methods, was used as a guide. This support system was designed to provide a minimum movement induced either by wave forces or currents. However, the shallow depth of the installation resulted in two failures due to wave forces (see Appendix I). These failures together with electronic or mechanical failures in the meters (see log, Appendix I) resulted in some incomplete data. The time series analysis was therefore restricted to periods of continuous data for both meters. The incomplete data months appearing in the tables are duly noted in the headings for each month.

The meters used in the study were calibrated in the river flow laboratory of the University of Toronto. For details of the calibrations see the Commission report entitled "Currents in the Nanticoke Region of Lake Erie, 1968".

Analytical Procedures

Data from the recording current meters and the recording anemometer at Toronto Island were analyzed using standard time series techniques for hourly average readings (Panofsky, 1958). Hourly readings were selected to eliminate any alaising effects (Blackman, 1958). Both current and wind vector directions are coming from: for example, direction 180° means it is COMING FROM the south. The frequency tables for currents,

winds, and temperatures are presented in Tables 2, 3 and 4. The average and resultant vectors with the number of readings used in each frequency analysis are presented in the lower part of each table. Ten minute reading intervals were used for the frequency analysis of currents and temperatures. Frequency analyses for winds were based on hourly readings. The persistence factors for currents and winds are also presented at the bottom of the tables. The persistence factor being defined as:

$$\text{Persistence} = P = \frac{\text{resultant current (magnitude of vector)}}{\text{mean current (magnitude of arithmetic mean)}}$$

The persistence factor would thus be 1.0 if the current was from the same direction for the whole month, while it would be 0.0 if the current was equally from all directions, or half the time from one and the other half from the opposite direction.

A velocity of 3.35 cm/sec. was required to overcome the meter propeller inertia. Thus, only velocities of 5 cm/sec. or greater were accurately recorded. Readings in the range of 0.3 to 5 cm/sec. shown in frequency tables are based on an integrated value over a period of ten minutes during which time velocities above and below the propeller inertial threshold (3.35 cm/sec.) could have occurred. Values below the threshold value are therefore valid in the frequency tables.

Autocorrelations were performed on the monthly data for time lags from 0 to 60 hours. A maximum lag of 60 hours was chosen on the basis of 5 to 10 per cent of the monthly records (Blackman, 1958). Some filtering of the data was achieved by converting 10 minute interval readings

to hourly values through the use of the moving average technique (Blackman, 1958). Fourier transforms were taken of the autocorrelations and the results were smoothed by Hanning to produce the energy spectra. The purpose of the energy spectra is to provide some indication of the underlying physical current generating parameters operative in the area. The confidence intervals for the energy spectra were arrived at by making the usual normality assumptions and applying a Chisquare distribution (Panofsky, 1958). This method produced a factor of 1.63 for the five per cent probability level which means that the variance density value multiplied by 1.63 has only a five per cent probability of being outside that range.

A time series analysis of the data was also carried out to produce cross-correlations for time lags of 0 to 60 hours between currents at the two meters; wind and currents at both meters. Coherence is analogous to the correlation coefficient squared but is a function of frequency. To obtain a measure of coherence between the two parameters, the data was analyzed to obtain Cospectra and Quadrapture for lags of 0 to 60 hours. The significance of the coherence values was determined by computing the limiting coherence values at various probability levels (p. 158, Panofsky, 1958) based on one month's data and sixty hours, the longest lag time utilized. For monthly records by hours, the five per cent limit is 0.424. In other words, there are only five chances in one hundred that a coherence value of 0.42 will occur purely by chance.

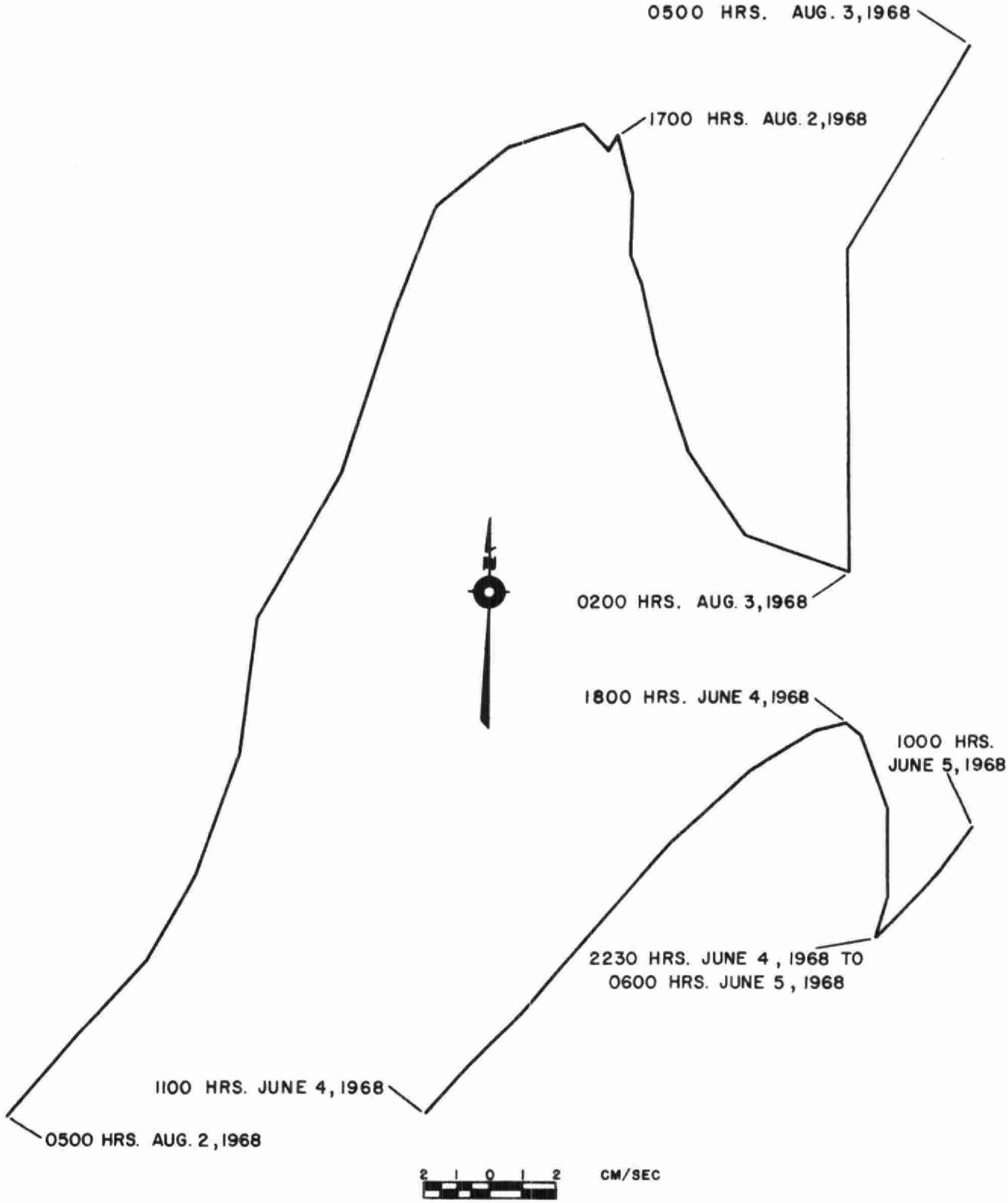


FIG. 3

CURRENTS IN THE FRENCHMAN BAY AREA OF LAKE ONTARIO - 1968

METER 012 — ACCUMULATED HOURLY CURRENTS

OWRC DWG. Nº 69-82-GL

DISCUSSION OF RESULTS

A summary of the current, wind and temperature frequencies along with the persistency factors are shown below. This is based on detailed results presented in Tables 2, 3 and 4.

TABLE 1-A

SUMMARY OF CURRENTS

Month	Description of Velocity (cm/sec)	Meter 011	Meter 012
June	Maximum velocity	14.4	12.63
	Period of zero velocity	0.21	0.33
	Period of velocity greater than 12 cm/sec.	0.005	0.005
	Resultant velocity	0.414 at 207°	0.551 at 167°
July	Maximum velocity	12.83	-
	Period of zero velocity	0.21	-
	Period of velocity greater than 12 cm/sec.	0.002	-
	Resultant velocity	0.762 at 167°	-
August	Maximum velocity	21.64	15.03
	Period of zero velocity	0.09	0.11
	Period of velocity greater than 12 cm/sec.	0.047	0.015
	Resultant velocity	1.190 at 63°	0.863 at 106°

TABLE 1-B

SUMMARY OF WINDS

Month	Description of Velocity (m/sec.)	Toronto Island Airport
June	Maximum velocity	13.38
	Period of zero velocity	0.051
	Period of velocity greater than 10.7 m/sec.	0.695
	Resultant wind and direction	0.13 at 30°
July	Maximum velocity	10.70
	Period of zero velocity	0.062
	Period of velocity greater than 10.7 m/sec.	0.269
	Resultant wind and direction	1.728 at 222°
August	Maximum velocity	11.15
	Period of zero velocity	0.067
	Period of velocity greater than 10.7 m/sec.	0.134
	Resultant wind and direction	0.664 at 262°

TABLE 1-C

SUMMARY OF WATER TEMPERATURE (°C)

Month	Temperature	Meter 011	Meter 012
June	maximum-minimum	14.5 to 4.0	14.8 to 4.0
	mean	6.85	7.35
	standard deviation	2.03	2.36
July	maximum-minimum	11.5 to 4.0	-
	mean	6.94	-
	standard deviation	1.04	-
August	maximum-minimum	17.5 to 3.9	18.0 to 6.5
	mean	11.56	13.78
	standard deviation	3.49	3.19

The difference in currents at the two depths demonstrates that water nearer to the free surface achieves smaller maximum velocities and has longer periods of little or no water movement. This would indicate that wind was not a major factor. The maximum current velocity of 21 cm/sec. was recorded in August. This is significantly lower than the 40 cm/sec. maximum recorded off Toronto in the fall of 1966 (Hamblin, 1967) and the maximum of 40 cm/sec. recorded further offshore in 1967 (Weiler, 1968). Stronger currents would normally be expected in the near shore areas, however, it appears that the confines of the shoreline and bottom significantly reduce the currents in the Frenchman Bay area. This is significant since it means that the currents in the area of the power plant are smaller than the general lake movements. The resultant transport of water masses out of the bay will consequently be less than other adjacent lakeshore areas.

The directions of the monthly resultant current transport vectors are generally in agreement with those found by Hamblin (1967) and Weiler (1968). In particular, the change of direction for August agrees well with similar results obtained by Hamblin (1967) in the Toronto area for September.

A summary of the persistence factors is presented below which agree with those determined by Hamblin (1967):

PERSISTENCE FACTORS

Month	Wind	Meter 011	012
June	0.03	0.24	0.36
July	0.47	0.42	-
August	0.17	0.29	0.23

The fact that both the directions of the resultant vectors and the persistence factors agree with other similar studies in adjacent areas tends to confirm the findings of this study. It further substantiates the conclusion that the bay reduces the currents in the local area.

A summary of the current and wind spectra is presented below.

TABLE 5

CURRENT AND WIND SPECTRA SUMMARY
OF SIGNIFICANT PERIODS IN HOURS

Month	Direction	Meters 011	012	Wind
June	E-W	23.0	21.0	11.5
	N-S	13.33	None	20.0
		6.87		11.5
		3.87		
July	E-W	18.5	-	None
		12.5		
	N-S	15.0	-	20.0
		7.06		10.5
August	E-W	15.5	13.3	11.5
		10.5	6.3	8.0
		6.3		
		3.8		
	N-S	15.5	16.0	20.0
		10.5	9.5, 5.5	11.0
		6.4	3.5, 2.2	5.2

The free oscillation periods for Lake Ontario for the respective modes are 4.91, 2.97, 2.15 and 1.63 hours (Rockwell, 1966) while the inertial period is 17.3 hours (Weiler, 1968). The local bay response time of 0.4 hours (Defant, 1961) is too small to be detectable in this study. With the exception of the repeated appearance of the diurnal and semi-diurnal periods there is no generally consistent periodic occurrence of currents. This is in agreement with the spectra determined for Toronto in 1966 (Hamblin, 1967) but in conflict with the results of a water level study at Hamilton (Hamblin, 1968) and current spectra determined farther offshore where Weiler (1968) found significant peaking with spectra at the inertial period. It is interesting to note that the inertial period of 17.1 hours consistently appears in the cross-correlations between currents and temperatures (see Table 7). From the current spectra periods it is difficult to decide what fundamental driving physical mechanisms are responsible for water movements in the area. It appears to be a combination as well as some direct shore influences (see Fig. 3). This is surprising when one considers the well-defined periods of spectra found in the Nanticoke study, (Palmer, 1968) on Lake Erie. But, it has also been noted by others (Noble, 1967 and Verber, 1966) who have pointed out some of the difficulties in applying spectral methods to current analysis.

The spectral analysis of the water temperatures is more revealing (see Table 6).

TABLE 6

TEMPERATURE SPECTRA SUMMARY
SIGNIFICANT PERIODS IN HOURS

Month		Meters 011	012
June	Grand Mean	13.5	13.3
	Daily Average	13.5	13.3
July	Grand Mean	18.0, 5.7 4.6	-
	Daily Average	18.0, 5.7 4.6	-
August	Grand Mean	16.0	3.0
	Daily Average	None	17.5, 9.2

The main mechanism in June appears to be a semi-diurnal effect while in July it is a combination of inertial and lake free oscillation effects. In August, only the inertial effects are evident. If the periods in Tables 5 and 6 are compared matching values can be found, but it is immediately evident that there are far fewer peaks in the temperature spectra.

A summary of the coherence spectra resulting from the cross-correlations is presented in Table 7. Unfortunately, due to incomplete data from meter 012 in July, it is only possible to consider June and August. Some coherence spectra are plotted in Figure 4.

TABLE 7

WIND, TEMPERATURE & CURRENT COHERENCE SUMMARY

Fig. No.	Factor A	Factor B	Periods With Significant (5%) Coherences (hrs.)
		JUNE	
4a	Meter 012-N	Meter 011-N	30.0, 10.0
4a	Meter 012-E	Meter 011-E	21.0, 14.3, 10.0
4b	Meter 012-N	Temp.-Grand Mean	17.1
4c	Meter 012-E	Temp.-Grand Mean	None
4b	Meter 012-N	Temp.-Daily Mean	17.1
4c	Meter 012-E	Temp.-Daily Mean	17.1
4d	Meter 011 Temp.-Grand Mean	Meter 012 Temp.-Grand Mean	15.0, 10.0 8.0, 5.0
4d	Meter 011 Temp.-Daily Mean	Meter 012 Temp.-Daily Mean	14.0, 9.1 5.0
	Meter 012-N	Wind-N	2.14
	Meter 012-E	Wind-E	None
	Meter 011-N	Wind-N	None
	Meter 011-E	Wind-E	None
		JULY	
	Meter 011-N	Wind-N	None
	Meter 011-E	Wind-E	None

TABLE 7 (cont'd)

Fig. No.	Factor A	Factor B	Periods With Significant (5%) Coherences (hrs.)
		AUGUST	
	Meter 012-N	Meter 011-N	None
	Meter 012-E	Meter 011-E	15.0, 8.0, 7.06, 6.00
4e	Meter 012-N	Temp.-Grand Mean	17.1, 7.0
4f	Meter 012-E	Temp.-Grand Mean	17.1, 13.3, 7.1
4e	Meter 012-N	Temp.-Daily Mean	16.0
4f	Meter 012-E	Temp.-Daily Mean	17.1
	Meter 012-N	Wind-N	2.67
	Meter 012-E	Wind-E	6.00
	Meter 011-N	Wind-N	None
	Meter 011-E	Wind-E	30.0

The coherence summary shows that there is no direct dependence of currents on winds in the area. Generally, the currents and temperatures of the two meters are correlated over many periods although the current cross-correlations are masked by the Ekman spiral effect with depth. The most significant coherence periods appearing are the inertial and diurnal types. In particular, the inertial period is the only one that appears consistently in the temperature cross-correlations indicating that temperature regimes are mainly a result of inertial forces.

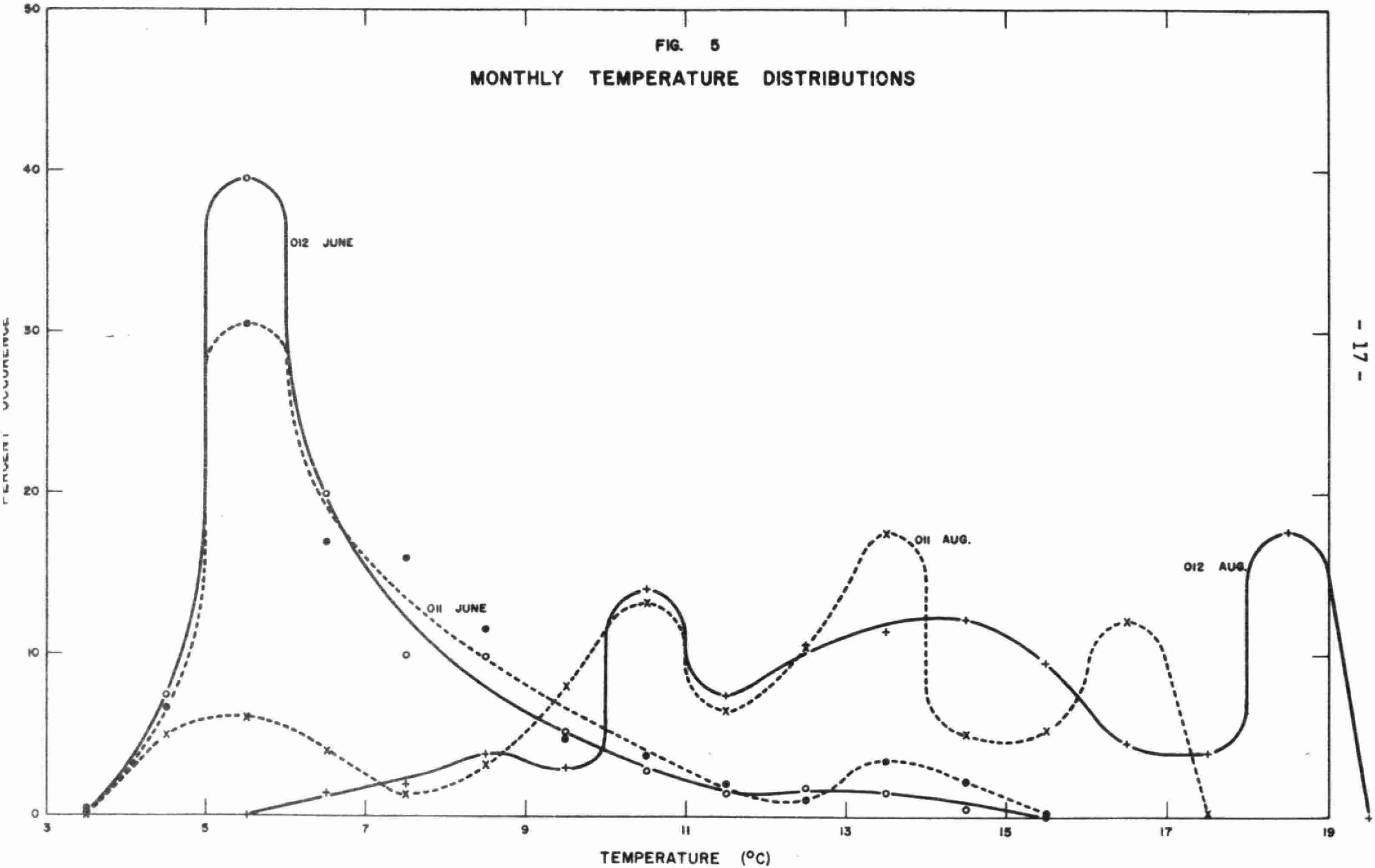


FIG. 5
MONTHLY TEMPERATURE DISTRIBUTIONS
012 JUNE
011 JUNE
011 AUG.
012 AUG.
TEMPERATURE (°C)

If the temperature distributions for June and August are plotted (see Fig. 5), the mean (first moment of area) temperature for the deeper meter 011 is less than the shallower meter 012 by 0.5° and $2.22^{\circ}C$ in June and August respectively (see Table 1). It is surprising that the standard deviation (second moment of area) of the temperature at the deeper Meter 011 is larger for August than Meter 012. Furthermore, while the skewed temperature distributions for June are consistent with other temperature distributions the multi-peaked distribution for August is unusual. Indeed it is the peaking that is responsible for the mean temperature phenomena mentioned previously. This may be evidence of some form of consistent sub-surface coastal jet (Csanady, 1968).

CONCLUSIONS

The most significant finding of this study was the observation that the magnitude of the currents is much less than currents determined by others in adjacent areas and farther offshore. Although both the persistence and directions of the currents in the study area are in agreement with findings by others; it appears that the confines of the bay reduce the water transport in the area. Granted, it could be argued that the findings of one current meter installation are not truly indicative of currents in the area. Since the meters were located in relatively deep water where there is no particularly unusual bottom configuration and were calibrated in a laboratory (Palmer, 1969), the observations can be considered representative of the area. Agreement in the current persistence factors and directions

with other studies tend to verify the findings. The findings have obvious implications as far as the discharge of waste and thermal effluents into the bay are concerned. as water movements in the area are less than regional movements.

The physical driving mechanisms responsible for the generation of currents were a mixture of diurnal, inertial and free oscillations of Lake Ontario forces in that order of significance. Wind did not appear to be directly responsible for currents in the area. The thermal regimes in the area were fundamentally a result of inertial effects.

Currents nearer the bottom had higher maximum values but were less persistent that currents nearer the surface. This phenomena could not be explained although it is suspected that some form of sub-surface coastal jetting may be operative. On a continuous discharge basis, the surface water layers have consistent dispersion characteristics.

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TABLES AND FIGURES

TABLE 2 A

FREQUENCY TABLE - METER 011

DIRECTION (IN DEGREES)

23 - 30 MAY, 1968

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49
0.00 - 0.30	0.232	0.309	0.386	0.309	0.309	0.463	0.463	0.0	0.309	1.313	1.081	1.467
0.31 - 2.99	2.625	2.317	0.849	1.467	1.544	0.695	0.618	1.004	1.699	3.320	4.633	2.008
3.00 - 5.99	1.931	0.541	1.158	0.541	0.695	0.463	0.618	1.853	2.548	3.166	2.548	0.541
6.00 - 8.99	0.0	0.0	0.232	0.154	0.386	0.077	0.463	1.467	1.699	1.622	0.541	0.077
9.00 - 11.99	0.0	0.0	0.077	0.154	0.077	0.309	0.772	1.622	1.390	0.463	0.077	0.0
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.232	0.463	0.232	0.309	0.0	0.0
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	4.788	3.166	2.703	2.625	3.012	2.008	3.166	6.409	7.876	10.193	6.880	4.093

	172.5 - 187.49	187.5 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	0.849	1.390	1.004	0.849	1.004	0.772	1.236	1.699	1.313	0.849	0.772	0.077	18.456
0.31 - 2.99	1.158	2.857	0.695	0.849	1.931	2.239	2.780	1.622	2.239	3.089	2.934	3.166	48.340
3.00 - 5.99	0.232	0.386	0.772	0.463	0.772	0.541	0.077	0.0	0.0	0.0	0.154	0.232	20.232
6.00 - 8.99	0.077	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.795
9.00 - 11.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.942
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.236
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	2.317	4.633	2.471	2.162	3.707	3.552	4.093	3.320	3.552	3.938	3.861	3.475	100.000

RESULTANT CURRENT IS 1.428 CM/SEC. AT 113° DEGREES. MEAN CURRENT IS 2.83 CM/SEC. PERSISTANCE IS 0.54

TOTAL NO. READINGS 1295 MAXIMUM CURRENT IS 14.430 CM/SEC.

TABLE 2 B

FREQUENCY TABLE - METER 011

DIRECTION (IN DEGREES)

JUNE, 1968

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49
0.00 - 0.30	1.460	0.997	0.765	0.371	0.579	0.533	0.255	0.278	0.672	0.927	1.576	1.854
0.31 - 2.99	1.993	2.619	2.271	2.063	1.367	1.831	0.821	1.136	1.112	1.553	2.202	2.735
3.00 - 5.99	0.579	1.136	1.367	0.649	1.066	1.136	0.626	0.417	0.556	0.278	0.255	0.371
6.00 - 8.99	0.209	0.487	0.417	0.139	0.116	0.046	0.116	0.116	0.070	0.0	0.0	0.093
9.00 - 11.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.023	0.0
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	4.241	5.238	4.820	3.221	3.129	3.546	1.877	1.947	2.410	2.758	4.056	5.052

SPEED (CM/SEC.)	172.5 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	2.132	1.831	1.645	0.811	0.324	0.440	0.510	0.394	0.348	0.394	0.973	0.950	21.020
0.31 - 2.99	3.917	4.565	4.542	3.615	2.665	2.804	2.063	1.251	1.066	0.927	1.437	2.039	52.654
3.00 - 5.99	0.672	2.572	3.662	2.433	1.159	1.066	0.440	0.185	0.394	0.371	0.348	0.255	21.993
6.00 - 8.99	0.278	0.510	0.556	0.301	0.023	0.116	0.070	0.185	0.116	0.023	0.0	0.093	4.079
9.00 - 11.99	0.046	0.046	0.023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.070	0.209
12.00 - 14.99	0.046	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.046
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	7.092	9.525	10.429	7.161	4.171	4.426	3.082	2.016	1.924	1.715	2.758	3.407	100.000

RESULTANT CURRENT IS 0.414 CM/SEC. AT 207 DEGREES. MEAN CURRENT IS 1.92 CM/SEC. PERSISTANCE IS 0.24

TOTAL NO. READINGS 4315 MAXIMUM CURRENT IS 14.430 CM/SEC.

TABLE 2 c

FREQUENCY TABLE - METER 011

DIRECTION (IN DEGREES)

JULY, 1968.

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49 -	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49	
0.00 - 0.30	0.537	0.403	0.291	0.470	0.291	0.604	0.627	1.164	1.119	1.477	1.723	1.623	
0.31 - 2.99	1.029	1.678	1.432	1.812	1.589	1.656	2.014	2.059	1.902	2.909	4.252	5.460	
3.00 - 5.99	0.246	0.627	1.007	1.186	1.253	0.649	0.515	0.358	0.448	0.470	.0.582	1.432	
6.00 - 8.99	0.045	0.067	0.291	0.738	0.179	0.022	0.0	0.0	0.022	0.0	0.045	0.201	
9.00 - 11.99	0.0	0.0	0.0	0.134	0.090	0.0	0.0	0.0	0.0	0.0	0.0	0.045	
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18.99 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN SUMS	1.880	2.775	3.021	4.341	3.401	2.931	3/155	3.580	3.491	4.856	6.601	8.772	

	172.5 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	0.716	0.940	0.850	0.515	0.537	0.492	0.873	0.873	1.119	1.141	1.387	1.119	20.900
0.31 - 2.99	5.549	6.086	3.379	1.947	1.499	1.902	1.745	1.633	1.298	1.029	1.275	1.141	56.277
3.00 - 5.99	2.663	2.461	1.335	0.738	0.291	0.559	0.291	0.112	0.224	0.067	0.045	0.0	18.058
6.00 - 8.99	0.940	1.208	0.537	0.045	0.0	0.022	0.0	0.0	0.0	0.0	0.0	0.0	4.363
9.00 - 11.99	0.022	0.067	0.0	0.0	0.0	0.0	0.022	0.0	0.0	0.0	0.0	0.0	0.380
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.022
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	9.890	10.763	6.501	3.245	2.327	2,976	2.931	2.618	2.640	2.238	2.708	2.260	100.000

RESULTANT CURRENT IS 0.762 CM/SEC. AT 107° DEGREES. MEAN CURRENT IS 1. 6 0 CM/SEC. PERSISTANCE IS 0. 4 2

TOTAL NO. READINGS 4469 MAXIMUM CURRENT IS 13.830 CM/SEC.

TABLE 2 D

FREQUENCY TABLE - METER 011

DIRECTION (IN DEGREES)

AUGUST, 1968 (FIRST THREE WEEKS)

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49	
0.00 - 0.30	0.725	0.423	0.362	0.393	0.332	0.272	0.151	0.242	0.574	0.544	0.483	0.453	
0.31 - 2.99	1.571	0.936	1.842	1.540	1.963	1.389	0.815	0.936	1.420	1.540	1.661	2.205	
3.00 - 5.99	1.087	2.235	1.963	2.205	2.235	1.661	0.906	0.574	1.087	0.725	0.815	1.420	
6.00 - 8.99	0.544	2.054	1.722	1.631	1.117	0.664	0.393	0.030	0.634	0.211	0.604	0.664	
9.00 - 11.99	0.121	1.148	0.483	0.815	0.544	0.242	0.030	0.0	0.0	0.060	0.272	0.423	
12.00 - 14.99	0.030	0.453	0.966	0.453	0.272	0.060	0.0	0.0	0.0	0.0	0.060	0.211	
15.00 - 17.99	0.0	0.151	0.906	0.302	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.030	
18.00 - 20.99	0.0	0.060	0.544	0.091	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN SUMS	4.077	7.460	8.619	7.430	6.463	4.289	2.295	1.782	3.715	3.081	3.896	5.406	
	172.5 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	0.815	0.574	0.362	0.332	0.272	0.393	0.181	0.272	0.332	0.332	0.393	0.242	9.453
0.31 - 2.99	2.668	2.628	1.933	2.084	1.782	0.997	0.646	0.725	0.755	0.678	1.117	1.117	35.367
3.00 - 5.99	3.141	1.420	1.661	1.722	1.329	0.615	0.574	0.272	0.362	0.393	0.755	0.634	29.991
6.00 - 8.99	1.752	1.087	0.574	0.453	0.393	0.211	0.060	0.030	0.030	0.151	0.242	0.121	15.373
9.00 - 11.99	0.393	0.242	0.121	0.030	0.060	0.0	0.0	0.0	0.0	0.0	0.060	0.060	5.104
12.00 - 14.99	0.060	0.030	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.597
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.389
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.695
COLUMN SUMS	8.849	5.980	4.651	4.621	3.836	2.416	1.661	1.299	1.480	1.752	2.567	2.175	100.000

RESULTANT CURRENT IS 1.190 CM/SEC. AT 63° DEGREES. MEAN CURRENT IS 4.06 CM/SEC. PERSISTANCE IS 0.29

TOTAL NO. READINGS 3311 MAXIMUM CURRENT IS 21.640 CM/SEC.

TABLE 2 E

FREQUENCY TABLE - METER 012

DIRECTION (IN DEGREES)

23 - 31 MAY, 1968.

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49	
0.00 - 0.30	2.315	1.157	0.309	0.231	0.386	0.231	0.617	1.157	1.312	1.389	1.389	3.704	
0.31 - 2.99	3.549	2.778	1.466	0.540	1.080	0.617	0.309	1.543	1.698	1.157	3.009	5.864	
3.00 - 5.99	0.077	0.231	0.154	0.077	0.154	0.309	0.386	0.617	0.617	0.386	2.006	3.472	
6.00 - 8.99	0.0	0.0	0.0	0.154	0.0	0.231	0.154	0.617	0.231	0.694	0.540	0.540	
9.00 - 11.99	0.0	0.0	0.0	0.0	0.154	0.386	0.540	0.849	0.386	0.849	0.309	0.231	
12.00 - 14.99	0.0	0.0	0.0	0.0	0.231	0.154	0.154	0.694	0.309	0.463	0.0	0.0	
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.231	0.0	0.0	0.154	0.0	0.0	
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN SUMS	5.941	4.167	1.929	1.003	2.006	1.929	2.392	5.478	4.552	5.093	7.253	13.812	
	172.5 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	3.549	1.466	1.003	1.312	0.772	1.775	1.003	1.080	0.849	0.617	1.003	0.617	28.244
0.31 - 2.99	5.170	2.083	2.778	1.620	1.080	2.469	4.321	2.238	1.543	0.463	0.617	0.463	48.457
3.00 - 5.99	1.235	0.154	0.617	0.617	0.694	0.077	0.154	0.077	0.0	0.154	0.154	0.231	12.654
6.00 - 8.99	0.077	0.0	0.0	0.077	0.0	0.0	0.0	0.0	0.0	0.077	0.0	0.0	3.395
9.00 - 11.99	0.0	0.0	0.0	0.0	0.077	0.0	0.0	0.0	0.0	0.077	0.0	0.0	3.858
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.006
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.386
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	10.031	2.704	4.398	3.627	2.623	4.321	5.478	3.395	2.392	1.389	1.775	1.312	100.000

RESULTANT CURRENT IS 1.178 CM/SEC. AT 138° DEGREES. MEAN CURRENT IS 2.08 CM/SEC. PERSISTANCE IS 0.57

TOTAL NO. READINGS 1296 MAXIMUM CURRENT IS 16.[illegible] CM/SEC.

TABLE 2 F

FREQUENCY TABLE - METER 012

DIRECTION (IN DEGREES)

JUNE, 1968

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49	
0.00 - 0.30	0.788	0.858	1.901	2.179	1.414	1.298	0.742	0.719	0.812	0.788	1.043	1.113	
0.31 - 2.99	0.904	1.136	3.037	3.988	2.179	1.623	0.951	0.812	1.090	1.067	1.322	1.716	
3.00 - 5.99	0.070	0.139	0.696	1.901	1.067	0.858	0.626	0.649	0.696	0.904	1.182	0.626	
6.00 - 8.99	0.0	0.046	0.093	0.023	0.070	0.023	0.185	0.417	0.232	0.209	0.255	0.185	
9.00 - 11.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.139	0.139	0.046	0.0	0.0	
12.00 - 14.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.023	0.0	0.0	0.0	0.0	
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN SUMS	1.762	2.179	5.727	8.092	4.730	3.802	2.504	2.759	2.968	3.014	3.802	3.640	

	172.50 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 337.49	337.50 352.49	ROW SUMS
0.00 - 0.30	0.719	2.458	5.240	3.153	2.272	1.855	1.067	0.371	0.742	0.672	0.556	0.556	33.318
0.31 - 2.99	1.577	3.153	9.321	5.565	2.713	1.275	0.510	0.255	0.394	0.301	0.696	0.580	46.163
3.00 - 5.99	0.325	0.927	2.179	1.924	1.391	0.510	0.209	0.023	0.209	0.116	0.093	0.0	17.320
6.00 - 8.99	0.162	0.232	0.093	0.162	0.023	0.116	0.139	0.116	0.023	0.0	0.0	0.0	2.805
9.00 - 11.99	0.0	0.023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.348
12.00 - 14.99	0.0	0.023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.046
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	2.782	6.817	16.833	10.805	6.399	3.756	1.924	0.765	1.368	1.090	1.345	1.136	100.000

RESULTANT CURRENT IS 0.551 CM/SEC. AT 167° DEGREES. MEAN CURRENT IS 1.52 CM/SEC. PERSISTANCE IS 0.36

TOTAL NO. READINGS 4313 MAXIMUM CURRENT IS 12.630 CM/SEC.

TABLE 2 G

FREQUENCY TABLE - METER 012

DIRECTION (IN DEGREES)

AUGUST, 1968

SPEED (CM/SEC.)	352.5 - 7.49	7.50 - 22.49	22.50 - 37.49	37.50 - 52.49	52.50 - 67.49	67.50 - 82.49	82.50 - 97.49	97.50 - 112.49	112.50 - 127.49	127.50 - 142.49	142.50 - 157.49	157.50 - 172.49	
0.00 - 0.30	1.080	0.691	0.432	0.475	0.432	0.475	0.562	0.475	0.043	0.302	0.562	0.778	
0.31 - 2.99	2.117	1.857	0.950	0.994	0.821	1.469	0.907	0.734	0.950	1.037	2.894	3.240	
3.00 - 5.99	1.469	2.376	2.203	2.333	2.117	1.944	1.555	1.382	1.166	1.857	2.549	2.981	
6.00 - 8.99	0.691	0.821	0.605	0.864	1.123	1.037	0.734	0.734	0.994	0.648	1.037	0.734	
9.00 - 11.99	0.302	0.302	0.432	0.518	0.216	0.302	0.173	0.432	0.389	0.173	0.043	0.173	
12.00 - 14.99	0.0	0.0	0.0	0.0	0.043	0.043	0.043	0.043	0.216	0.302	0.086	0 .043	
15.00 - 17.99	0.0	0.0	0.0	0.043	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN SUMS	5.659	6.048	4.622	5.227	4.752	5.270	3.974	3.801	3.758	4.320	7.171	7.948	
	172.5 - 187.49	187.50 - 202.49	202.50 - 217.49	217.50 - 232.49	232.50 - 247.49	247.50 - 262.49	262.50 - 277.49	277.50 - 292.49	292.50 - 307.49	307.50 - 322.49	322.50 - 337.49	337.50 - 352.49	ROW SUMS
0.00 - 0.30	1.555	0.432	0.0	0.043	0.130	0.259	0.130	0.173	0.216	0.518	0.605	0.605	10.972
0.31 - 2.99	2.376	1.512	0.691	0.216	0.475	0.259	0.389	0.475	0.907	1.210	2.376	1.901	30.756
3.00 - 5.99	1.598	1.685	1.210	0.994	1.425	1.080	0.691	0.475	0.605	1.253	0.821	0.907	36.674
6.00 - 8.99	0.432	0.389	0.475	0.950	0.302	0.475	0.346	0.173	0.518	0.216	0.259	0.389	14.946
9.00 - 11.99	0.346	0.0	0.302	0.346	0.086	0.173	0.389	0.043	0.0	0.0	0.0	0.043	5.184
12.00 - 14.99	0.216	0.130	0.216	0.043	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.425
15.00 - 17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.043
18.00 - 20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	6.523	4.147	2.894	2.592	2.419	2.246	1.944	1.339	2.246	3.197	4.060	3.844	100.000

RESULTANT CURRENT IS 0.863 CM/SEC. AT 106° DEGREES. MEAN CURRENT IS 3.77 CM/SEC. PERSISTANCE IS 0.23

TOTAL NO. READINGS 2315 MAXIMUM CURRENT IS 15.030 CM/SEC.

TABLE 3A
WIND FREQUENCY - MAY 1968
DIRECTION

SPEED meters/sec	337.50°-22.49°	22.50°-67.49°	67.50°-112.49°	112.50°-157.49°	157.50°-202.49°	202.50°-247.49°	247.50°-292.49°	292.50°-337.45°	Row Sums
0.00 - 1.33	1.075	0.403	1.613	.941	1.075	.941	.403	.134	6.586
1.34 - 2.94	.538	0.672	3.495	.806	2.554	3.091	3.360	1.344	15.860
2.95 - 4.01	.538	2.151	5.511	.403	3.091	2.688	2.151	7.258	23.790
4.02 - 5.34	.672	2.823	4.704	0.000	1.613	0.269	0.538	8.065	18.683
5.35 - 6.68	.672	3.226	4.167	0.000	1.344	0.672	0.538	4.167	14.785
6.69 - 8.02	0.000	2.957	1.613	0.000	0.672	0.941	0.538	2.419	9.140
8.03 - 9.35	0.000	2.823	0.941	0.000	0.134	0.538	0.269	0.403	5.108
9.36 -10.69	0.000	1.075	0.269	0.000	0.000	0.269	0.134	0.000	1.747
10.70 -12.01	0.000	1.075	0.134	0.000	0.000	0.134	0.000	0.000	1.344
12.02 -13.35	0.000	1.075	0.000	0.000	0.000	0.000	0.000	0.000	1.075
13.36 -14.70	0.000	1.210	0.000	0.000	0.000	0.000	0.000	0.000	1.210
14.71 -16.02	0.000	0.672	0.000	0.000	0.000	0.000	0.000	0.000	0.672
COLUMN SUMS	3.495	20.161	22.446	2.151	10.484	9.543	7.930	23.790	100.000

Resultant speed is 1.499 m/sec at 30 degrees.
Total number of readings is 720 (hourly).

Mean speed is 4.56 m/sec. Persistence is 0.33
Maximum speed is 15.590 m/sec.

TABLE 3B
WIND FREQUENCY - JUNE 1968
DIRECTION

SPEED meters/sec	337.50°-22.49°	22.50°-67.49°	67.50°-112.49°	112.50°-157.49°	157.50°-202.49°	202.50°-247.49°	247.50°-292.49°	292.50°-337.49°	ROW SUMS
0.00 - 1.33	.556	0.000	.833	.417	.556	1.667	1.111	0.000	5.139
1.34 - 2.94	.972	.833	3.750	1.250	4.167	9.861	2.778	1.389	25.000
2.95 - 4.01	0.000	.833	7.222	.694	3.611	7.500	2.222	4.167	26.250
4.02 - 5.34	.139	2.083	5.417	0.000	1.806	2.917	1.389	3.611	17.361
5.35 - 6.68	.417	1.667	3.194	.139	2.639	.833	.972	2.222	12.083
6.69 - 8.02	.139	3.056	1.111	.139	1.111	.556	1.111	1.111	8.333
8.03 - 9.35	0.000	1.806	.139	0.000	.417	.556	.833	0.278	4.028
9.36 -10.69	0.000	.417	0.000	0.000	0.000	0.000	.417	0.278	1.111
10.70 -12.01	0.000	.278	0.000	0.000	0.000	0.000	0.000	0.000	0.278
12.02 -13.35	0.000	.278	0.000	0.000	0.000	0.000	0.000	0.000	0.278
13.36 -14.70	0.000	.139	0.000	0.000	0.000	0.000	0.000	0.000	0.139
14.71 -16.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COLUMN SUMS	2.222	11.389	21.667	2.639	14.306	23.889	10.833	13.056	100.000

Resultant speed is .125 m/sec at 162 degrees.
Total number of readings is 720 (hourly).

Average speed is 3.89 m/sec. Persistence is 0.03.
Maximum speed is 13.38 m/sec.

TABLE 3C
WIND FREQUENCY - JULY 1968
DIRECTION

SPEED meters/sec	337.50°- 22.49°	22.50°- 67.49°	67.50°- 112.49°	112.50°- 157.49°	157.50°- 202.49°	202.50° 247.49°	247.50°- 292.49°	292.50°- 337.49°	ROW SUMS
0.00 - 1.33	.538	.134	1.344	0.000	.269	2.285	1.075	0.538	6.283
1.34 - 2.94	.403	.806	4.167	.941	3.360	9.005	3.629	2.151	24.462
2.95 - 4.01	.269	.672	5.108	.941	4.435	8.468	3.360	5.242	28.495
4.02 - 5.34	0.000	.134	2.957	.134	4.301	4.032	3.091	2.957	17.608
5.35 - 6.68	0.000	.538	0.806	.134	4.704	0.941	2.016	1.882	11.022
6.69 - 8.02	0.000	.269	0.538	.134	3.629	0.672	2.285	0.538	8.065
8.03 - 9.35	0.000	0.000	0.000	0.000	1.478	0.403	1.747	0.000	3.629
9.36 -10.69	0.000	0.000	0.000	0.000	0.000	0.134	0.134	0.000	0.269
0.70 -12.01	0.000	0.000	0.000	0.000	0.000	0.134	0.134	0.000	0.269
2.02 -13.35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.36 -14.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.71 -16.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OLUMN SUMS	1.210	2.554	14.919	2.285	22.177	26.075	17.473	13.306	100.000

esultant speed is 1.728 m/sec at 222 degrees.
Total number of readings is 744 (hourly).

Mean speed is 3.71 m/sec. Persistence is 0.47.
Maximum speed is 10.70 m/sec.

TABLE 3D
WIND FREQUENCY - AUGUST 1968
DIRECTION

SPEED meters/sec	337.50°- 22.49°	22.50°- 67.49°	67.50°- 112.49°	112.50°- 157.49°	157.50°- 202.49°	202.50°- 247.49°	247.50°- 292.49°	292.50°- 337.49°	ROW SUMS
0.00 - 1.33	.268	0.000	1.075	0.000	0.941	1.210	2.285	0.941	6.720
1.34 - 2.94	.538	.538	3.763	.403	2.419	5.511	4.301	4.032	21.505
2.95 - 4.01	.806	1.882	4.435	1.210	5.511	4.167	2.688	6.048	26.747
4.02 - 5.34	.269	2.554	2.554	0.269	4.301	1.478	0.941	4.973	17.339
5.35 - 6.68	0.000	3.495	2.151	0.000	3.898	1.210	1.882	4.032	16.667
6.69 - 8.02	0.000	1.334	0.672	0.134	1.478	0.403	2.285	2.285	8.602
8.02 - 9.35	0.000	0.269	0.000	0.000	0.134	0.538	0.403	0.538	1.882
9.36 -10.69	0.000	0.000	0.000	0.000	0.000	0.134	0.269	0.000	0.403
0.70 -12.01	0.000	0.000	0.000	0.134	0.000	0.000	0.000	0.000	0.134
2.02 -13.35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.36 -14.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.71 -16.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OLUMN SUMS	1.882	10.081	14.651	2.151	18.683	14.651	15.054	22.849	100.00

esultant speed is 0.664 m/sec at 262 degrees.
Total No. of readings is 744 (hourly).

Mean speed is 3.83 m/sec. Persistence is 0.17.
Maximum speed is 11.15 m/sec.

TABLE 4

TEMPERATURE FREQUENCY

Temperature Range °C	May (1) Meter		June Meter		July Meter		August (2) Meter	
	011	012	011	012	011	012	011	012
0.0 - 3.99							0.18	
4.0 - 4.99			7.26	6.66	1.09		4.92	
5.0 - 5.99	7.94	4.17	39.66	30.45	19.97		6.38	
6.0 - 6.99	28.50	26.85	19.91	17.00	28.13		4.19	1.31
7.0 - 7.99	22.43	35.19	9.92	16.57	38.59		1.46	1.83
8.0 - 8.99	41.12	33.80	9.92	11.76	10.05		3.46	3.92
9.0 - 9.99			5.17	4.96	1.63		8.01	2.87
10.0 - 10.99			2.93	3.82	0.14		13.48	14.10
11.0 - 11.99			1.40	1.56	0.27		6.56	7.31
12.0 - 12.99			1.68	1.42			10.56	10.44
13.0 - 13.99			1.54	3.54			17.49	11.23
14.0 - 14.99			0.56	2.12			5.10	12.01
15.0 - 15.99							5.28	9.66
16.0 - 16.99					0.14		12.39	4.18
17.0 - 17.99							0.55	3.39
18.0 - 18.99								17.75
19.0 - 19.99				0.14				
20.0 - 20.99								
21.0 - 21.99								
22.0 - 22.99								
23.0 - 1000.0								
TOTALS	100	100	100	100	100		100	100

(1) Last week only.

(2) First three weeks only.

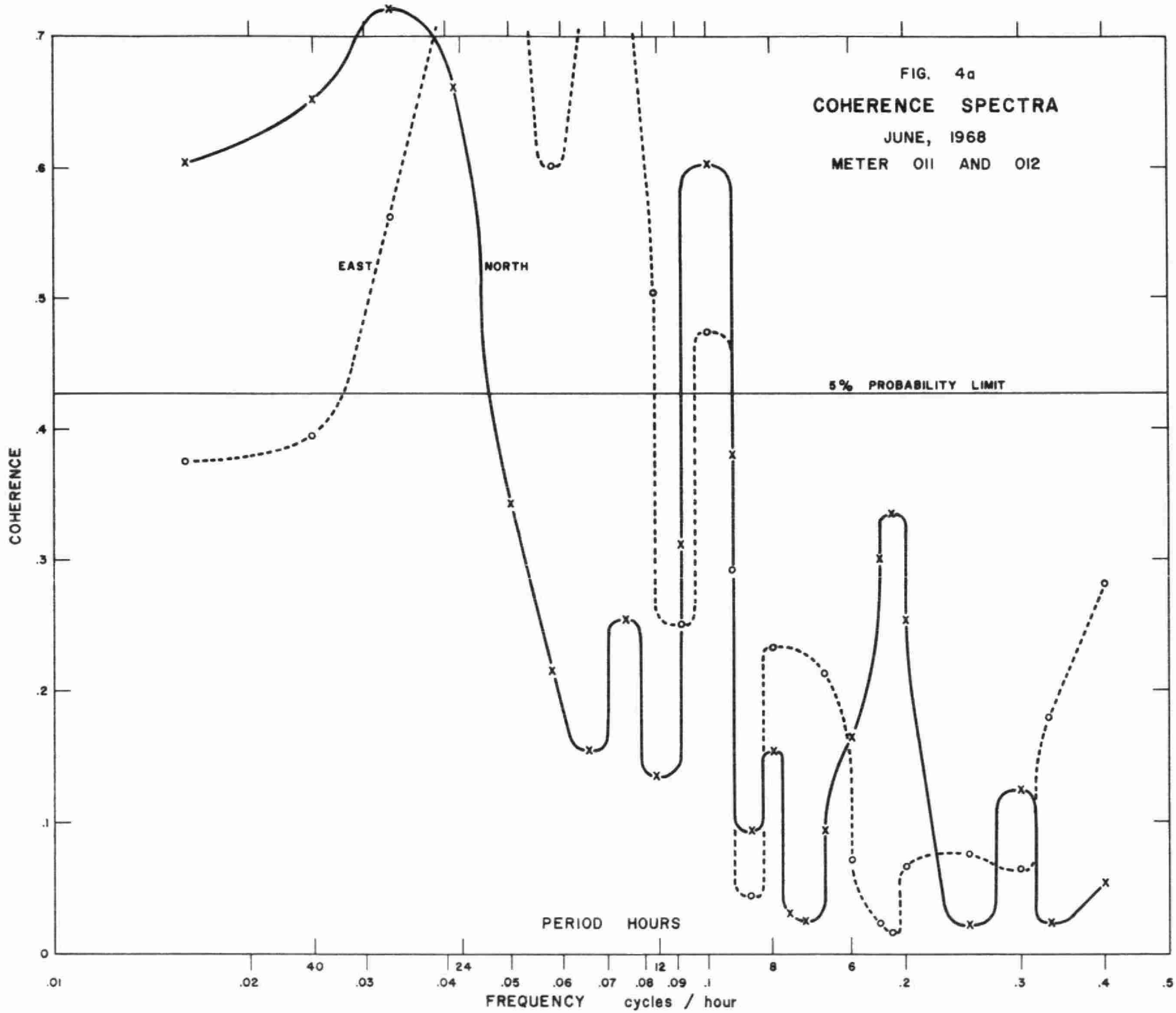
FIG. 4a
COHERENCE SPECTRA
JUNE, 1968
METER 011 AND 012
EAST
NORTH
5% PROBABILITY LIMIT
PERIOD HOURS
40
24
12
8
6
COHERENCE
0
.1
.2
.3
.4
.5
.6
.7
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
FREQUENCY cycles / hour

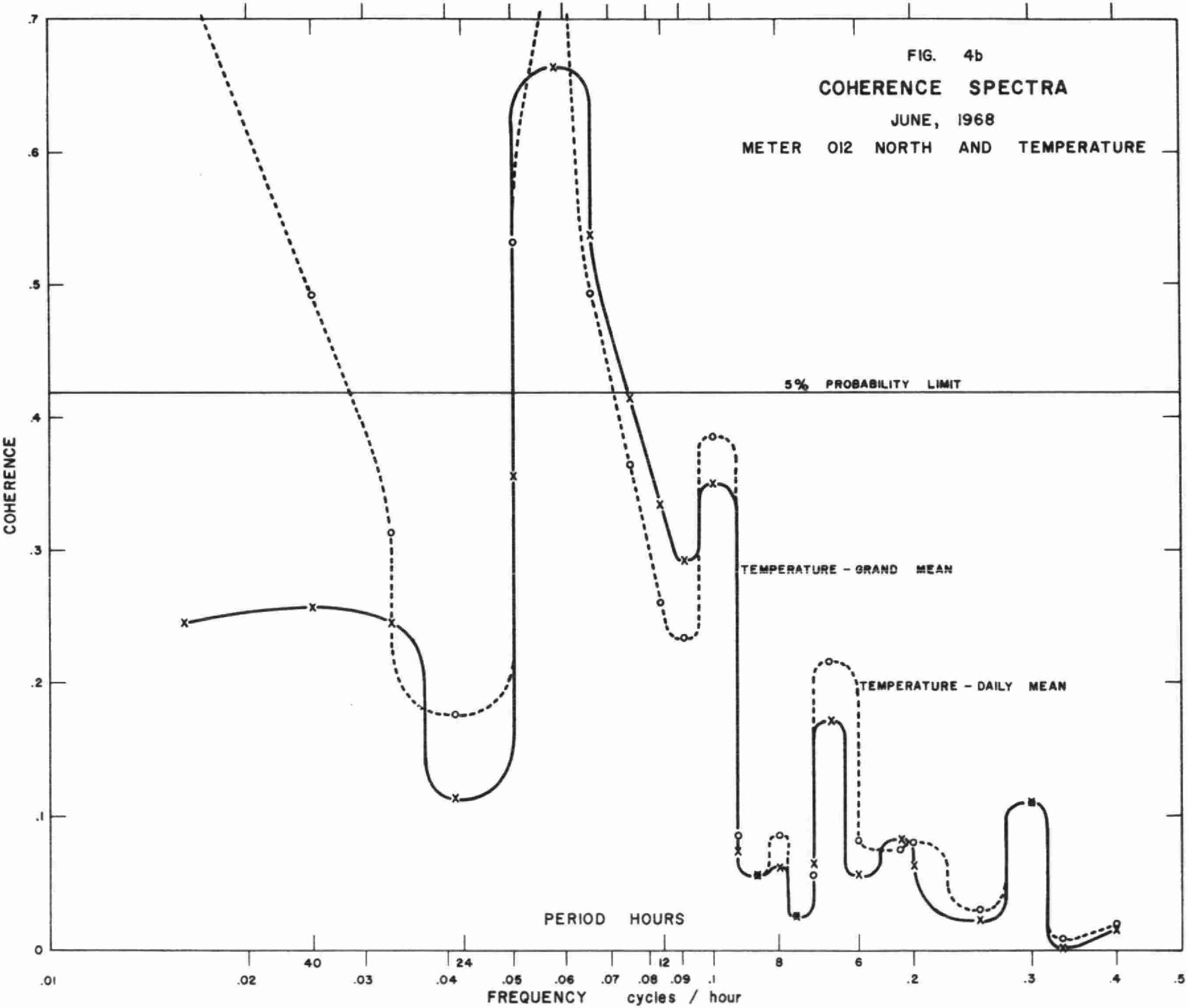

FIG. 4b
COHERENCE SPECTRA
JUNE, 1968
METER 012 NORTH AND TEMPERATURE
5% PROBABILITY LIMIT
TEMPERATURE - GRAND MEAN
TEMPERATURE - DAILY MEAN
COHERENCE
PERIOD HOURS
FREQUENCY cycles / hour
.7
.6
.5
.4
.3
.2
.1
0
40
24
12
8
6
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5

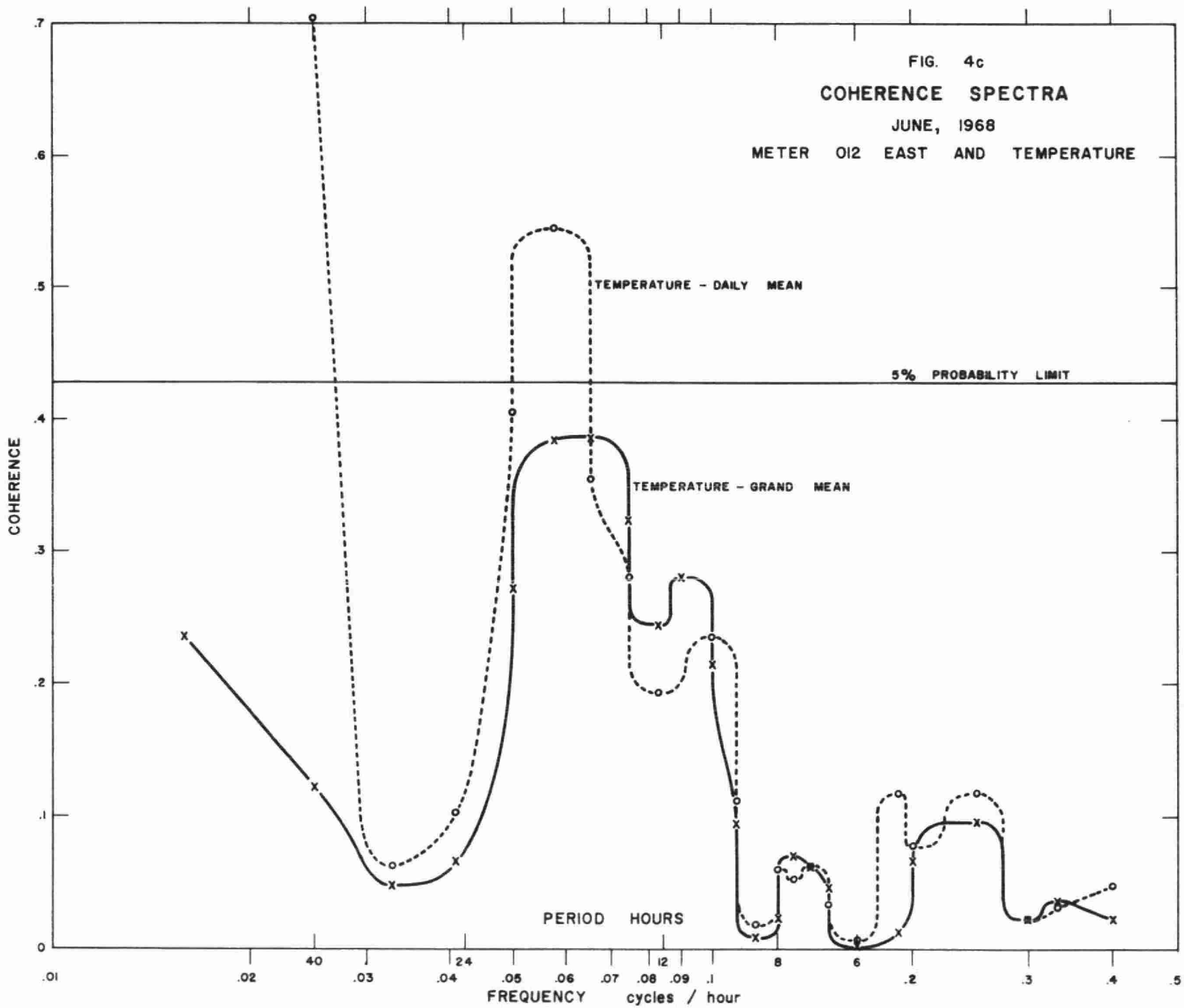
FIG. 4c
COHERENCE SPECTRA
JUNE, 1968
METER 012 EAST AND TEMPERATURE
TEMPERATURE - DAILY MEAN
5% PROBABILITY LIMIT
TEMPERATURE - GRAND MEAN
PERIOD HOURS
COHERENCE
FREQUENCY cycles / hour
.7
.6
.5
.4
.3
.2
.1
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
40
24
12
8
6

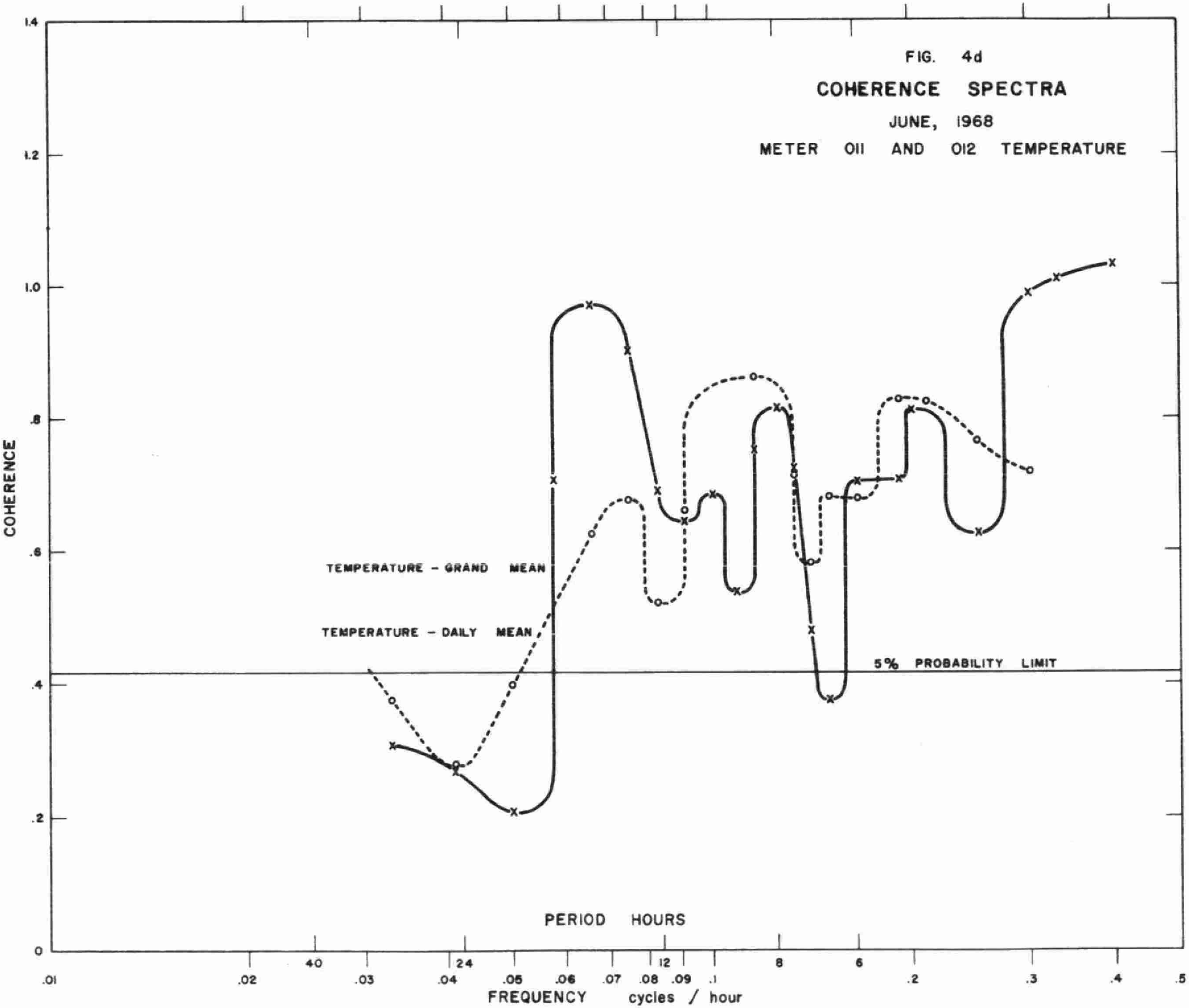

FIG. 4d
COHERENCE SPECTRA
JUNE, 1968
METER 011 AND 012 TEMPERATURE
COHERENCE
TEMPERATURE - GRAND MEAN
TEMPERATURE - DAILY MEAN
5% PROBABILITY LIMIT
PERIOD HOURS
FREQUENCY cycles / hour

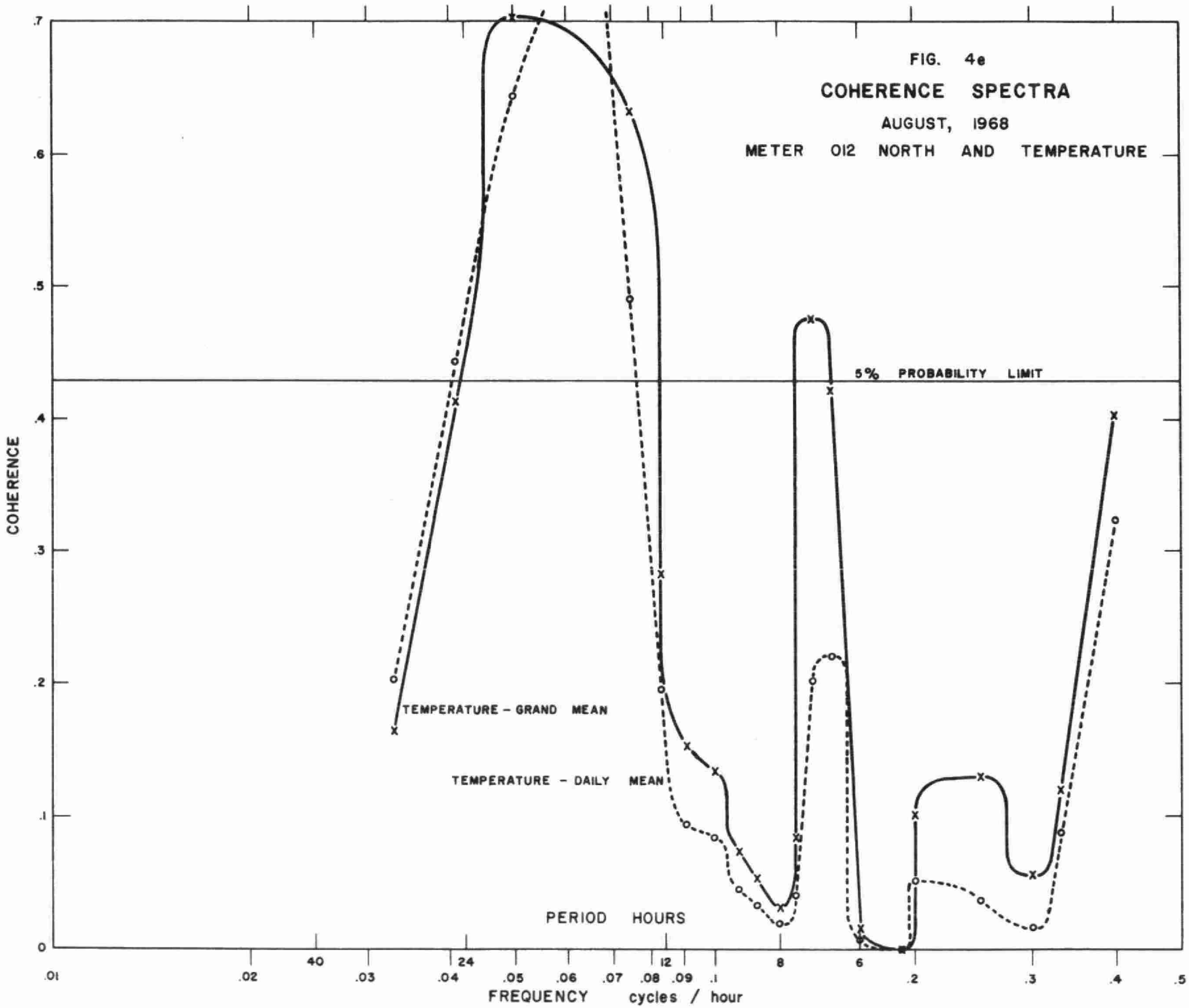
FIG. 4e
COHERENCE SPECTRA
AUGUST, 1968
METER 012 NORTH AND TEMPERATURE
5% PROBABILITY LIMIT
TEMPERATURE - GRAND MEAN
TEMPERATURE - DAILY MEAN
PERIOD HOURS
COHERENCE
FREQUENCY cycles / hour
.7
.6
.5
.4
.3
.2
.1
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
40
24
12
8
6

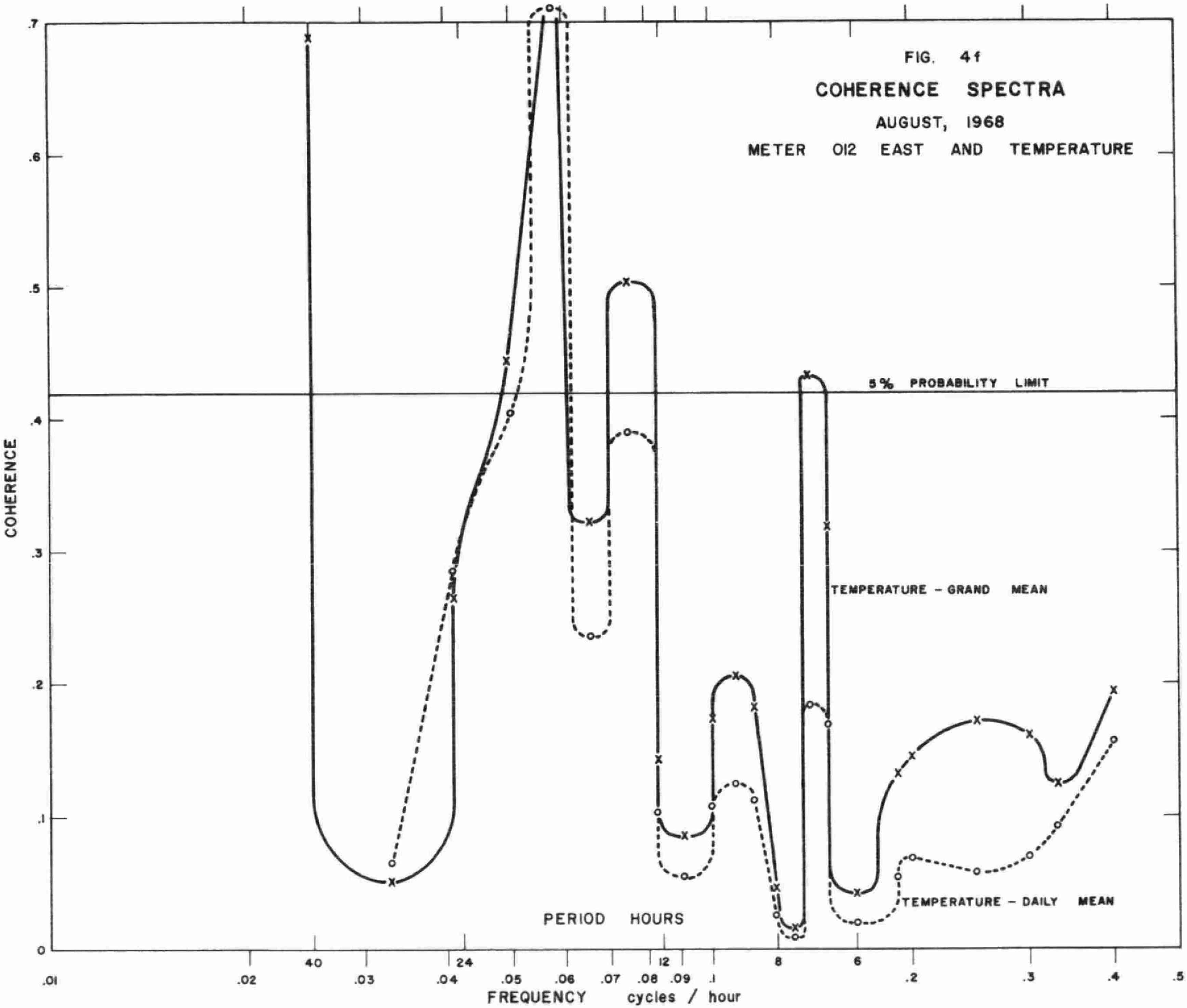

FIG. 4f
COHERENCE SPECTRA
AUGUST, 1968
METER 012 EAST AND TEMPERATURE
5% PROBABILITY LIMIT
TEMPERATURE - GRAND MEAN
TEMPERATURE - DAILY MEAN
PERIOD HOURS
40
24
12
8
6
COHERENCE
0
.1
.2
.3
.4
.5
.6
.7
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
FREQUENCY cycles / hour

APPENDIX I

METER 011 LOG

Location	79° 05' 00" W.
	43° 47' 54" N
Water Depth	12.7 m (42 feet)
Depth of meter	2.42 m (8 feet) from bottom

Meter Serial Number 164 Reference 261

Date	Time		Service
	In	Out	
May 22	17 29		Meter installed
May 30			Hydrophone Monitor[1]
May 30			Support system failure
June 3			Support system repaired
June 14	17 30	13 30	Tape replaced
July 8			Hydrophone monitor run
July 23	10 45	10 13	Meter replaced by Serial No. 159 inverting binary signals No. 164
August 6			Hydrophone monitor-- Signal garbled
August 16			Hydrophone monitor-- No. 159 O.K.
August 22		10 55	Meter removed
August 30	11 40		Meter No. 144 installed
September 2		08 20	Meter No. 144 removed

(1) Hydrophone monitor checks the operation of the meters in situ for malfunctioning.

APPENDIX I

METER 012 LOG

Location 79° 05' 00" W
43° 47' 54" N
Water Depth 12.7 m (42 feet)
Depth of meter 4.6 m (15 feet) from bottom

Meter Serial Number 162 Reference 228

Date	Time		Service
	In	Out	
May 22	17 33		Meter installed
May 30			Hydrophone Monitor
May 30			Support system failure
June 3			Support system repaired
June 14	17 30	13 30	Tape replaced and magnetic tape, take-up spoolproblem
July 8			Hydrophone Monitor Meter not transmitting
July 23	10 45	10 08	No. 144 Meter replaced No. 162
August 6			Hydrophone Monitor
August 16			Hydrophone Monitor
August 22		10 45	Meter removed No. 159 replaces No. 144
August 30	12 00	10 15	Tape punch wheel prob-lem corrected Hydrophone Monitor
September 21		08 15	Meter No. 159 removed

ADDENDUM

CURRENTS IN THE FRENCHMAN BAY AREA OF LAKE ONTARIO

1968

ADDENDUM

M. D. Palmer
February, 1970

INTRODUCTION

This addendum is intended as a supplement to the report "Currents in the Frenchman Bay area of Lake Ontario, 1968", OWRC. It provides no new data but does amplify the existing information.

This report contained the results of two recording current meters at different depths operated in Lake Ontario approximately three and a half kilometers offshore of Frenchman Bay in 12.7 meters of water from May to August, 1968. Measured currents, temperatures and winds are presented in the form of frequency tables, spectra and coherence functions (Palmer (4)). Subsequent to the printing of this report, methods have been developed to analyze the current data by other methods to produce monthly mean and hourly dispersion concentration contours (Palmer (5)). The current meter data from Frenchman Bay has been re-analyzed to generate these contours. A representation in this form makes it simplier to visualize what the dilution characteristics are in the area.

OUTLINE OF METHOD

Monthly Mean Dispersion Characteristics

The method is detailed in "Great Lakes Nearshore Modelling from Current Meter Data, 1969" (Palmer (5)). In summary, the auto-correlation functions for one month are integrated and operated on to produce mean spread values. The two-dimensional mean spread values, which are representative of the dispersion characteristics, are used in a dispersion equation which is solved at the nodal points of a rectangular grid of 225 metres spacing to determine concentration contours. Concentration contours represent the mean monthly values resulting from a continuous point discharge of 2.7×10^5 $cm^2/sec.$ (approximately 11 $ft.^2/sec.$). The patterns are developed from single fixed point current meter records extended to an area coverage by spatial cross-correlations with other meters. This method is two-dimensional assuming uniform distribution over unit depth or thin lamina theory. Published (Csanady (1)) values of the dispersion characteristics in the vertical direction (depthwise) in the shallow nearshore areas of the Great Lakes are of the order of 10 $cm^2/sec.$ which is at least two orders of magnitude less than the dispersion in the other two directions. The lamina (two-dimensional) theory appears justified. However, care must be taken in adapting flows per unit depth to area pipe discharges or manifold diffusers.

Hourly Dispersion Characteristics

The hourly dispersion characteristics are obtained by a Markov Chain process detailed in "Great Lakes Nearshore Modelling from Current Meter Data, 1969". In summary, the monthly current meter records are classified into 80 states (current classification). There are 10 equal speed classes with variable limits to suit the maximum value in the record and 8 direction classes. The states are numbered sequentially from the smallest velocity north 1 to 80. A one hour state transition probability matrix (first order Markov Chain) is determined. Given a state occurring now this matrix predicts the probability of any of the 80 possible states existing in the next hour. An initial state (state now) probability vector can be combined with the transition matrix to determine a new probability state vector which gives the probability of all 80 states after one hour. The method can be repeated successively employing the probability vectors determined at the end of each hour period as the initial probabilities for the next hour. The probabilities of occurrence of each state is now defined for each successive hourly period. For example, it is possible to determine the probability of the sequence state (0-3 cm/sec North) to state 1 to state 3 (0-3 cm/sec East) to state 10 (3-6 cm/sec N.E.) by examining the probabilities of the states occurring in each successive hourly vector.

As the currents are funadmental in the transport of dispersion of material, a knowledge of their characteristics provides an indication of the dispersion patterns. A weighted mean distance travelled in each of the eight directions can be obtained by using the state probabilities as wighing factors. The mid-point of the state velocity class is assumed to exist for one hour and converted to distance travelled in one hour. Weighing is obtained by modifying the distance travelled by the probability. The weighted distances travelled in each direction each hour can be plotted and the area enclosed by the hourly contours is representative of the dispersion characteristics for that time period. Dispersion characteristics determined in this manner do not differentiate between direction. However, the shape of the plotted hourly contours provide differentiation between directions.

Maximum and minimum characteristics can also be determined by examining various parts of the probability vectors. For example, an indication of minimum dispersions can be obtained by employing the first eight states only in the computations as these states represent the lowest velocities considered. Similarly, states greater than 41 can be considered as representative of the maximum dispersion.

RESULTS

Monthly Mean Dispersion Characteristics

The monthly mean dispersion patterns for Meters 011 June, July and August and Meter 012 June 1968 appear in Figures 1 to 4 respectively. (Meter 012 July and August are only a two week record and consequently could not be utilized). It is observed that the pattern is in a northerly direction for both meters except August which is southwest. It should be noted that the persistence factors (predominance in the direction plotted with 1.0 representing continuous movement in one direction) as well as the resultant velocities are small particularly at Meter 011 in June. The deeper Meter 011 June (Figure 1) pattern is less extensive and skewed to the east of the shallower Meter 012 (Figure 4).

This shifting of pattern appears similar to an Ekman spiral effect although caution is warranted on the basis of one month's concurrent record. The shift predicted by an Ekman spiral for a wind speed of 3.84 m/sec. at 44°N and a friction depth of 33.7 m is approximately 12 degrees (Neumann (2)) for a difference of depth of 2.2 metres, whereas Figures 1 and 3 show a 40 degree angle shift. The validity of the Ekman spiral can be questioned on the grounds that the plotted plumes represent monthly mean values and the cross-correlations between winds and currents are sporatic. Nevertheless,

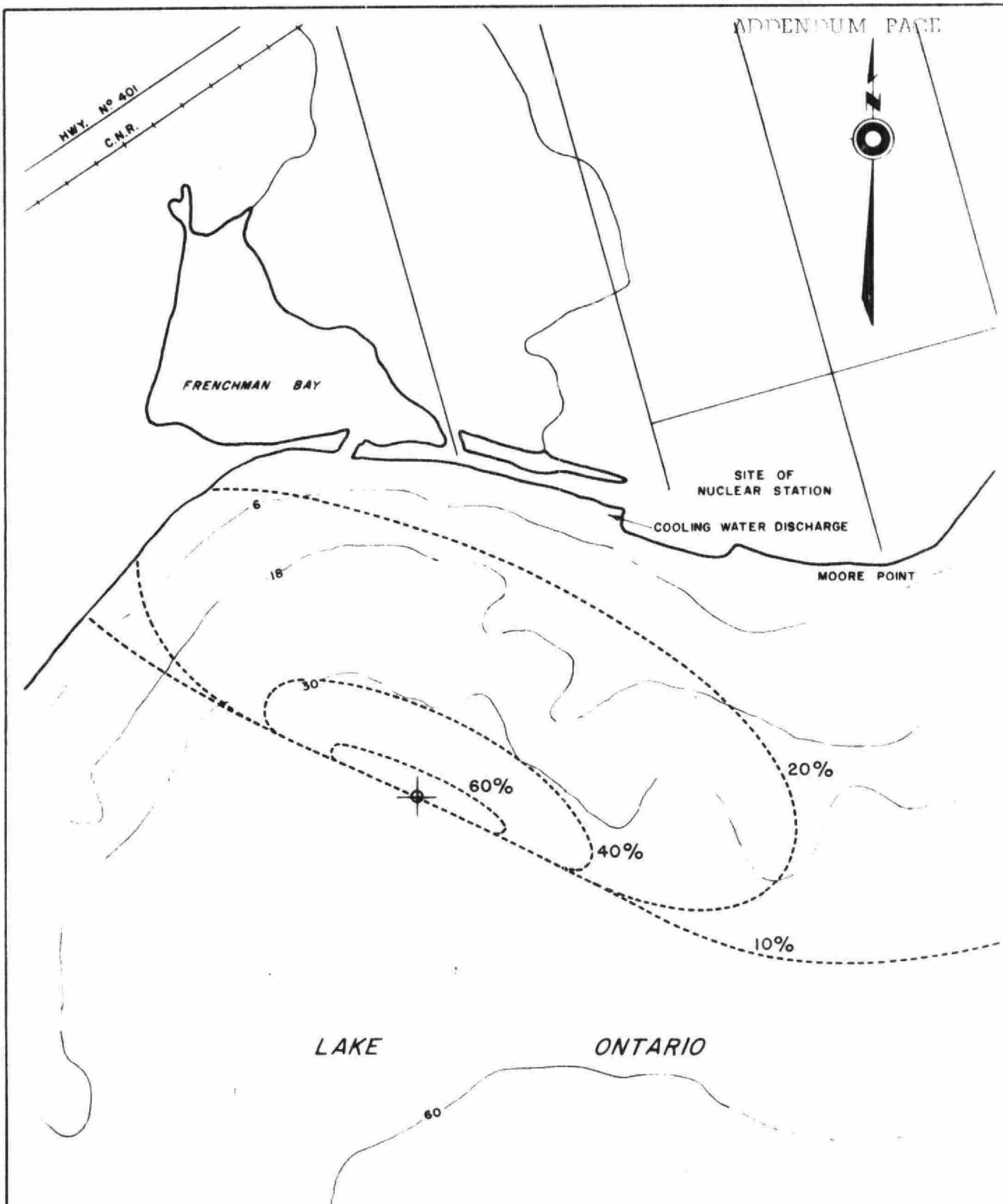

FIG. 1

METER 011
JUNE 1968
(DEEP)

CONCENTRATION CONTOURS
$Q = 2.71 \times 10^5$ cm^2 / sec.

PERSISTANCE = 0.24

ONTARIO WATER RESOURCES COMMISSION

MEAN MONTHLY
DISPERSION PATTERNS

SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S	DATE JUNE, 1969
CHECKED BY:	DRAWING Nº 70-36-GL

ADDENDUM PAGE

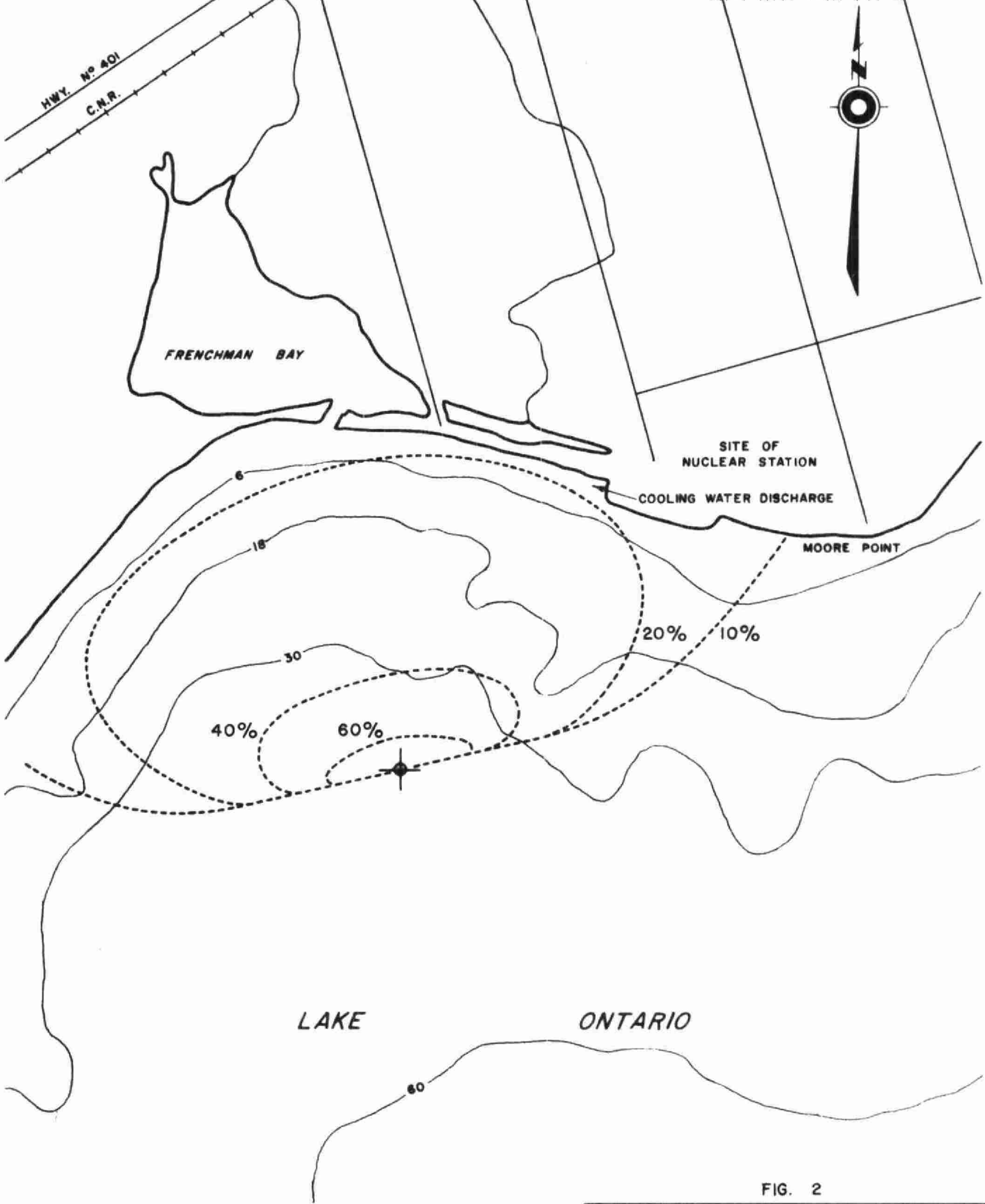

FIG. 2

METER 011
JULY 1968
(DEEP)

CONCENTRATION CONTOURS
$Q = 2.71 \times 10^5 \ cm^2 / sec.$

PERSISTANCE = 0.42

ONTARIO WATER RESOURCES COMMISSION	
MEAN MONTHLY DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-37-GL

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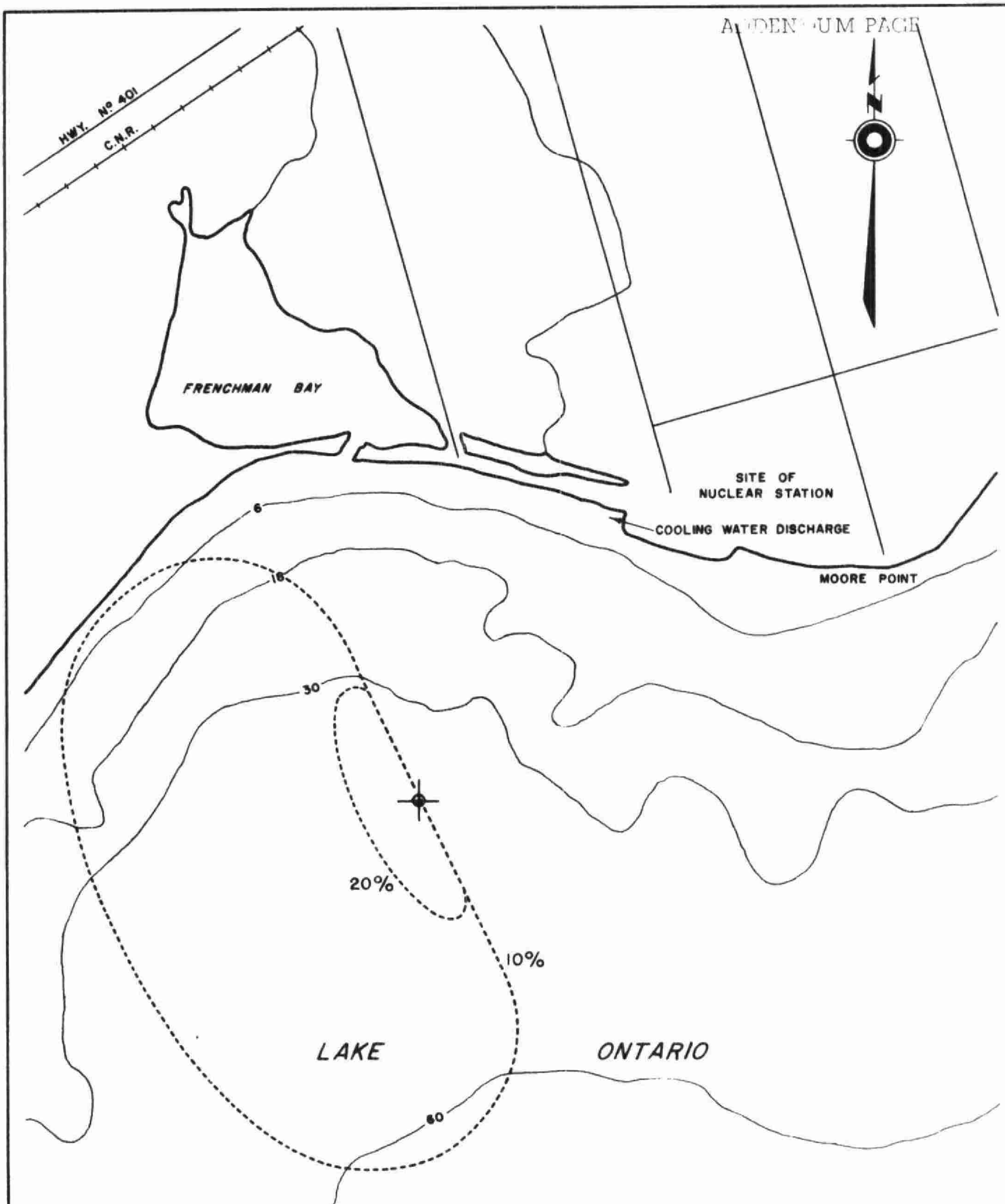

FIG. 3

METER 011
AUG. 1968
PICKERING

CONCENTRATION CONTOURS
$Q = 2.71 \times 10^5$ cm^2 / sec.

PERSISTANCE = 0.29

ONTARIO WATER RESOURCES COMMISSION	
MEAN MONTHLY DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-38-GL

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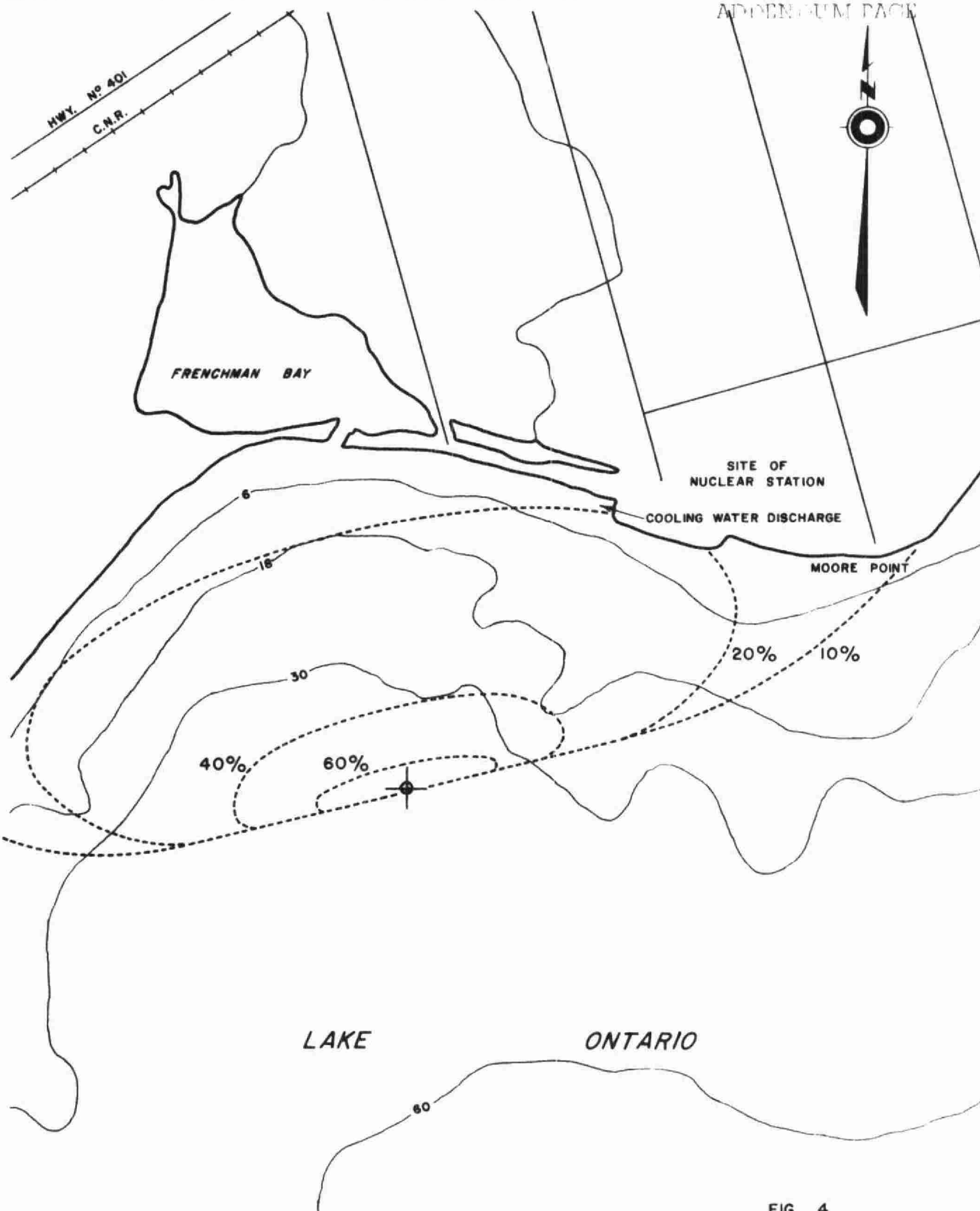


FIG. 4

METER 012
JUNE 1968
(SHALLOW)

CONCENTRATION CONTOURS
$Q = 2.71 \times 10^5 \ cm^2 / sec.$

PERSISTANCE = 0.36

ONTARIO WATER RESOURCES COMMISSION	
MEAN MONTHLY DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-39-GL

the direction shift and the reduced dispersion characteristics with depth are similar to that expected from an Ekman spiral.

The resultant onshore pattern is disturbing. It means that material discharges near the shore will remain in the confines of the bay for months like June and July. There would be negligible net transport of material out of the bay during this period. In other words, the bay is quite vulnerable to monthly accumulations as indicated by studies in June and July. The currents in the bay are very different from those at Nanticoke on Lake Erie where the resultant transport is from 2 to 10 times greater and predominantly parallel to the shore (Palmer (2)).

Hourly Dispersion Characteristics

The eight hour dispersion characteristics for the month of June and August appear in Figures 5 to 8 and Table 1.

TABLE 1

EIGHT HOUR DIFFUSIVITY COEFFICIENTS
METERS 011, 012
1968

		Diffusivity Coefficients (cm^2/sec.)		
Meter No.	Month	Minimum Dispersion	Mean Dispersion	Maximum Dispersion
011 deep	June	0.149×10^4	0.642×10^4	17.38×10^4
	August	0.0156×10^4	2.539×10^4	29.60×10^4
012 shallow	June	0.184×10^4	0.493×10^4	20.15×10^4
	August	0.0149×10^4	2.075×10^4	21.27×10^4

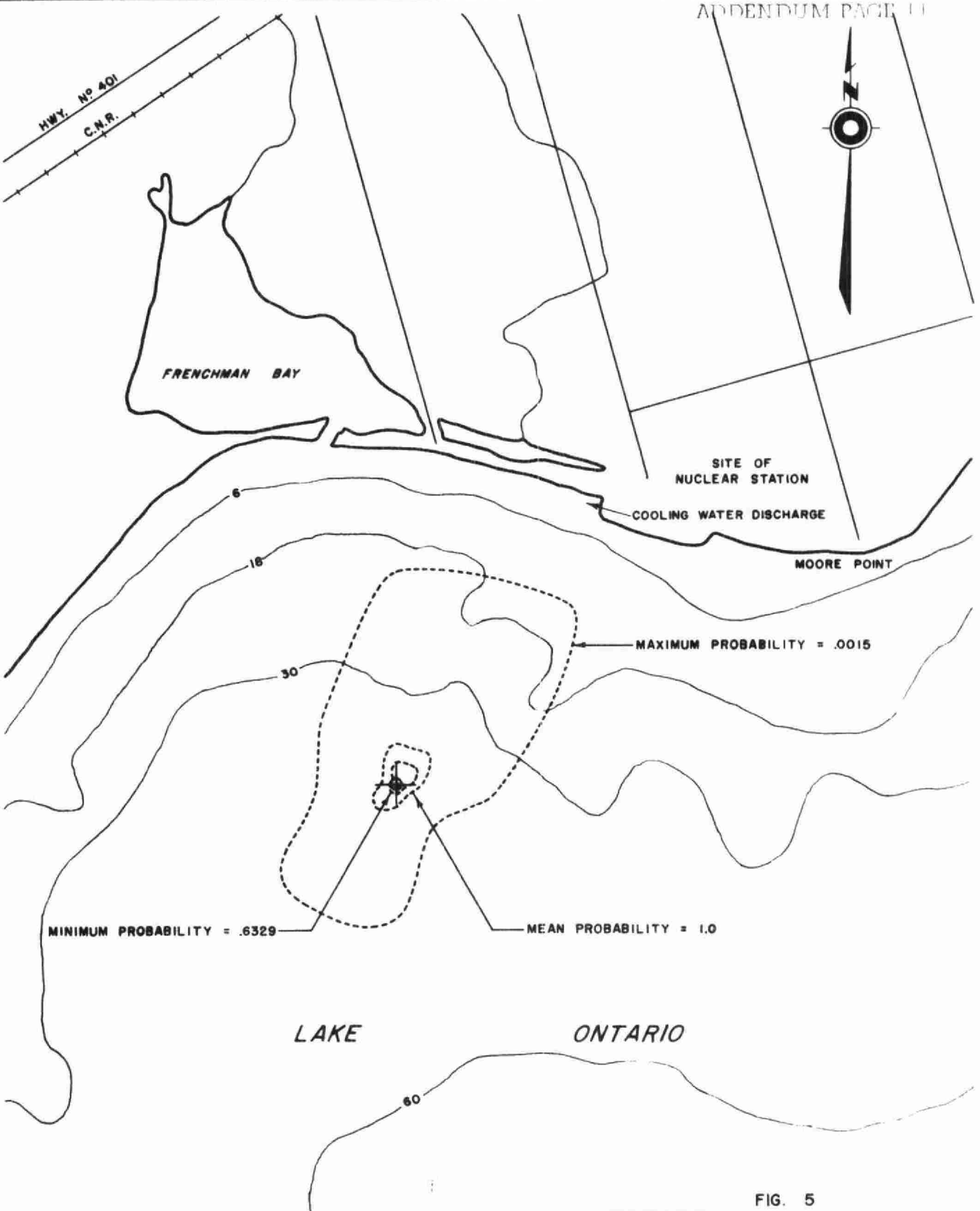


FIG. 5

ONTARIO WATER RESOURCES COMMISSION	
EIGHT HOUR DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-40-GL

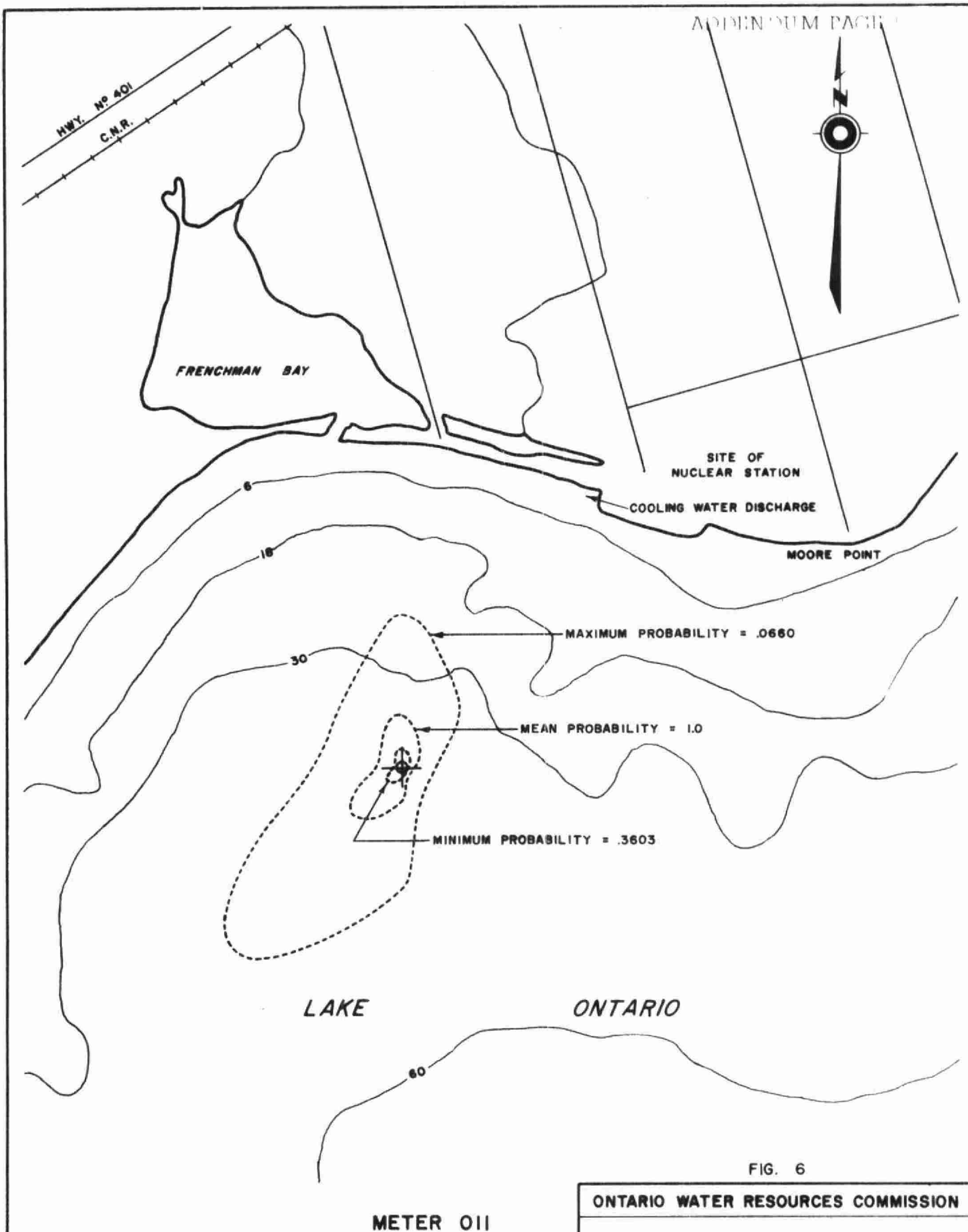
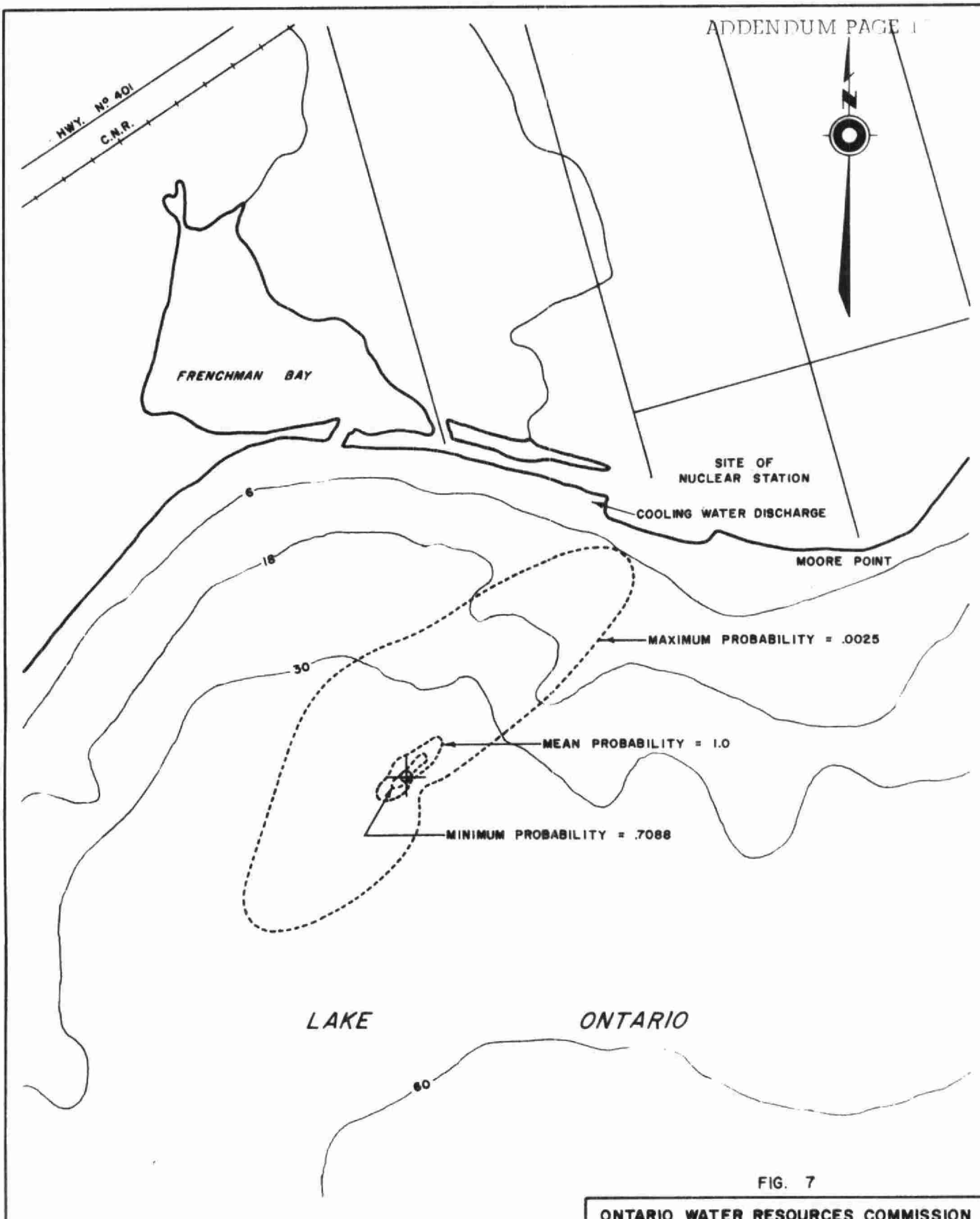


FIG. 6

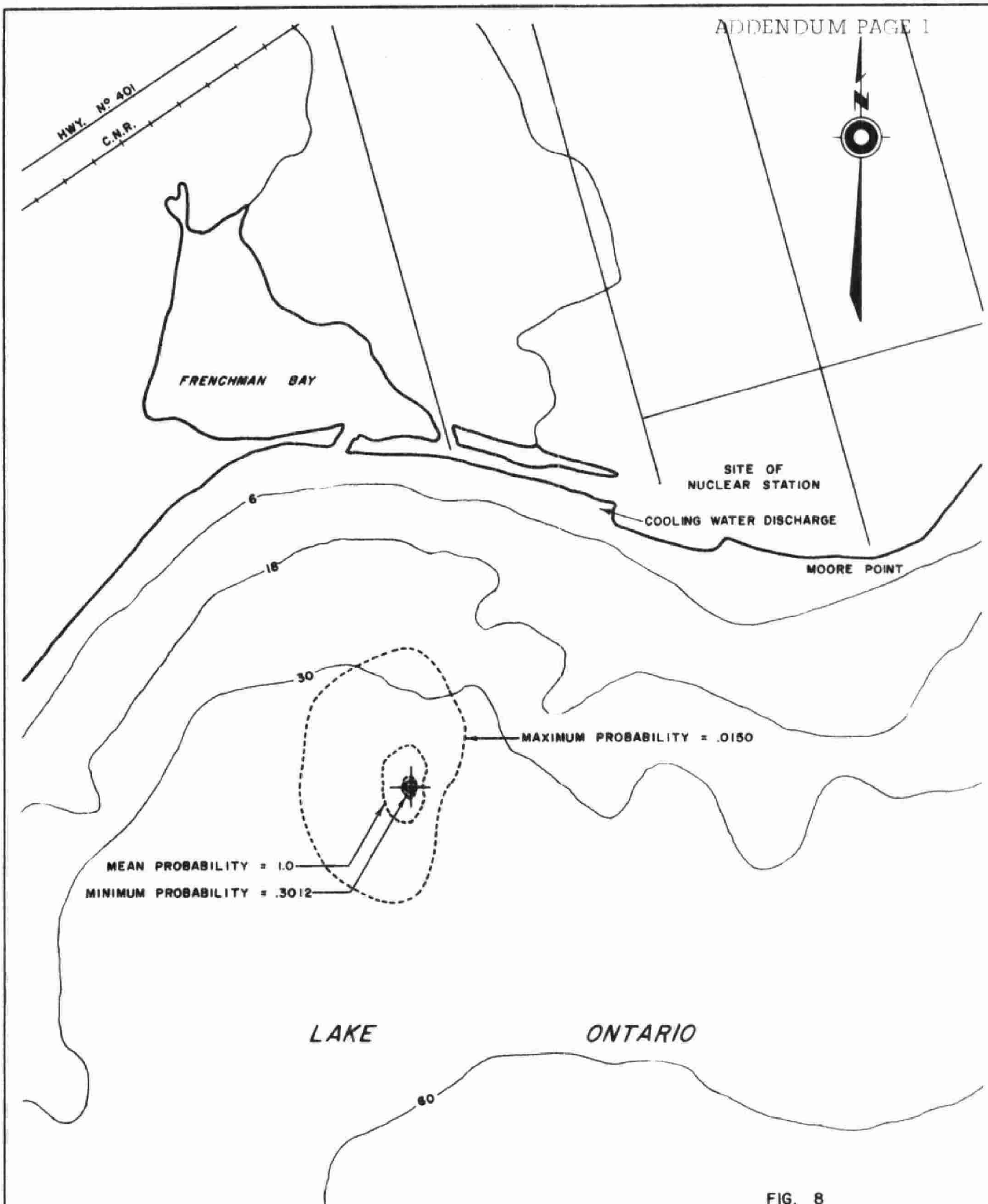
ONTARIO WATER RESOURCES COMMISSION	
EIGHT HOUR DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-41-GL



METER 012
JUNE 1968

FIG. 7

ONTARIO WATER RESOURCES COMMISSION	
EIGHT HOUR DISPERSION PATTERNS	
SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-42-GL



METER 012
AUG. 1968

FIG. 8

ONTARIO WATER RESOURCES COMMISSION

EIGHT HOUR
DISPERSION PATTERNS

SCALE: 0 1/8 1/4 3/8 1/2 MILES	
DRAWN BY: A.R.S.	DATE: JUNE, 1969
CHECKED BY:	DRAWING Nº: 70-43-GL

The angle shifting between the two meters is not evident here although the reduction of dispersion with depth is still observed. This is more readily observed in Table 1. The figures in Table 1 are much less than those obtained in Nanticoke but compare favourably with other values determined on Lake Huron (Csanady (1)) and Lake Erie (Okubo (3)).

CONCLUSIONS

Based upon measured currents in the area for June and July, the introduction of new waste discharges to the bay should be avoided unless other studies indicate better assimilative characteristics in the bay. It also appears that discharges near the surface will disperse better than deeper locations.

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Palmer, M D
Currents in
Frenchman Bay area   anme
of Lake Ontario c.1   a aa
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